SHEFFIELD'S TREES

Measuring the effects and benefits of the urban forest i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and community forestry analysis and benefits assessment tools, including i-Tree Eco. The Forest Service, Davey Tree Expert Company, National Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, and Casey Trees have entered into a cooperative partnership to further develop, disseminate and provide technical support for the suite.

For further information see www.itreetools.org

Treeconomics is a social enterprise, with a mission to highlight the benefits of trees and woodlands. Treeconomics develops projects with landowners, communities, academics and other stakeholders to quantify and value trees, green infrastructure and natural capital. Together we deliver sustainable urban forest management plans, tree and woodland valuation projects and consultancy that aim to improve our environment.

For further information see www.treeconomics.co.uk

Authors:

Kenton Rogers - Treeconomics

Annabel Buckland - Treeconomics

Dave Hansford - Treeconomics

Foreword

It is with great pleasure and satisfaction that I introduce this report because, due to climate change, increasing biosecurity threats, limited resources for the management and planting of trees and a growing population of people there will never be a more important time to develop and implement a strategy for managing all of our tree assets. This includes newly planted nursery stock, established, mature and veteran specimens within our landscape. Without this important data and information, it will be very difficult to create, maintain and preserve a healthy and diverse treescape both in the urban and rural parts of the city of Sheffield.

This informative and detailed report highlights the many benefits of the urban forest of Sheffield, showing that trees and woodland are a major asset to the urban environment and everyone that uses the city. The treescape of the Urban Forest must be planned, designed, and managed in a more integrated way to ensure residents and visitors reap the multitude of benefits they provide.

Sheffield's trees are becoming increasingly valuable as we face the challenges of climate change population growth and ongoing development. Trees also play an important role in promoting our mental and physical wellbeing, cooling our cities, reducing the heat island effect, filtering air pollution and reducing the risk of flooding, together with the ornamental attributes that all trees can provide.

Trees are our front line defence against climate change and we need to ensure that we have a diverse population and they are properly accounted for as a critical part of the urban infrastructure. The economic and social value of trees has become increasingly evident across the UK, highlighted by reports similar to this in various towns and cities.

Sheffield will have a vision over the next decade or two and into the next century, and whilst vision is important there is a need to know what tree stock we have now in order to plan to fulfil that vision, and this is what this report provides, a detailed and comprehensive snap shot in time of Sheffield's Urban Forest…. the start of a very important journey in securing a diverse and resilient treescape for generations to come.

Tony Kirkham VMH, MBE

Head of the Arboretum, Gardens and Horticultural Services, Royal Botanic Gardens, Kew.

Executive Summary

All of the many thousands of trees in Sheffield's urban realm; in parks, gardens, open spaces and amenity areas, in woodlands, along streets, railways and waterways, are collectively described as the 'urban forest'. This report provides a comprehensive picture of the structure and a conservative estimate of the value of Sheffield's urban forest.

The results presented in this report were collected through a stratified i-Tree Eco random sample exercise. 261 plots were surveyed by teams of trained volunteers and professionals across Sheffield, measuring land-use, ground-cover and over 1,200 trees. Information collected included species, height, diameter of the trunk and canopy spread. Using this data with iTree provides a quantitative baseline assessment of the air pollution, carbon storage, carbon sequestration, stormwater benefits and amenity value of the entire tree resource in Sheffield, accounting for the trees on both public and private land. Only part of the iTree software resource has been utilised in producing this report. There is much more data and additional functionality within the suite of iTree tools which goes beyond the scope of this assessment.

This detailed report provides the information necessary for the production of a comprehensive management plan for Sheffield's urban forest. It provides relevant information and recommendations to inform the council's tree strategy in the short, medium and long-term and provides the baseline information for ward level comparisons. Headline figures are presented in table 1, opposite.

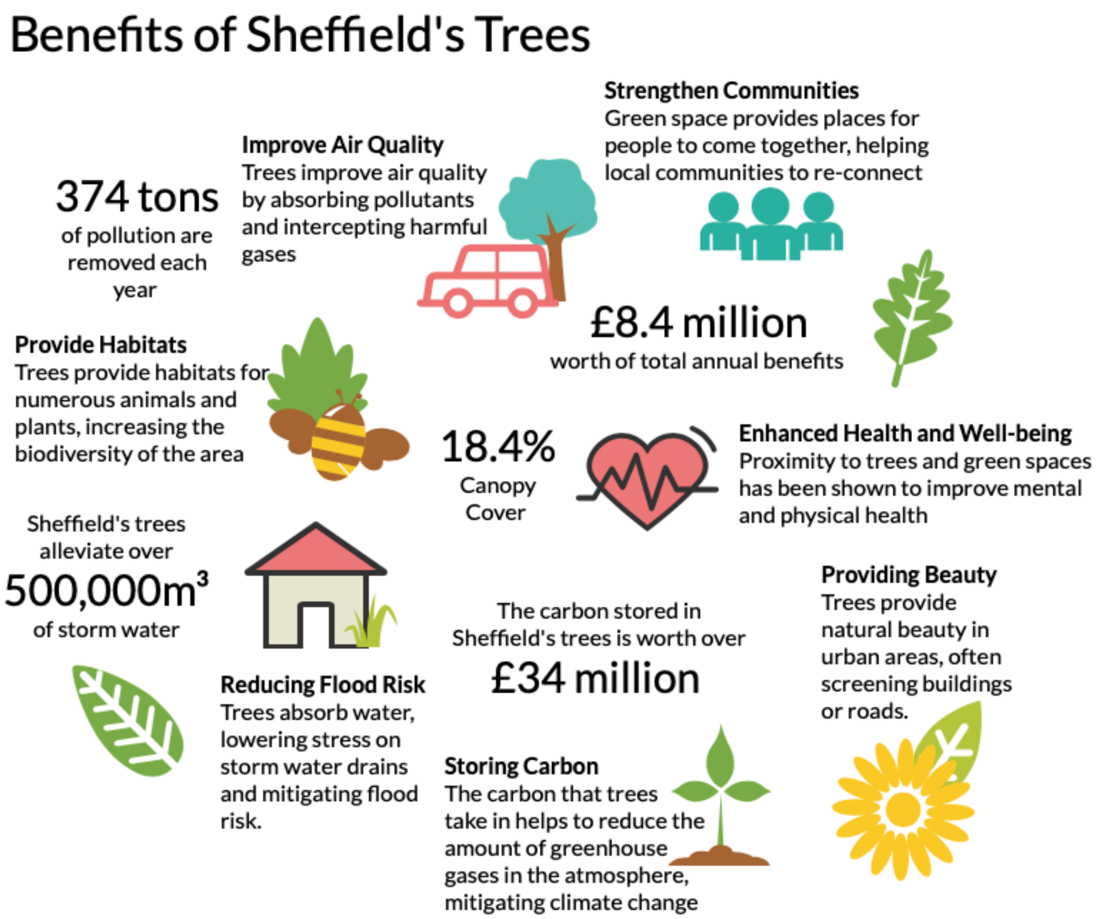

Fig 1. Benefits of Sheffield's Trees infographic

Headline Figures

		Total	
Number of Trees	Moorland	87,963	
	Urban	3,775,667	
	Study Area	3,863,630	
Tree Cover (not including shrubs)	Moorland	4.60%	
	Urban	21.60%	
	Study Area	18.40%	
Potential Plantable Space	Moorland	94.30%	
	Urban	48.60%	
	Study Area	57.10%	
Most Common Species	Moorland	Betula pendula, Quercus petraea, Crataegus monogyna	
	Urban	Betula pendula, Acer pseudoplatanus, Quercus petraea	
Replacement Cost	Moorland	£84,182,626	
	Urban	£1,347,951,322	
	Study Area	£1,432,133,948	
Amenity Value (CAVAT)	Study Area	£9,345,351,982	
Carbon Storage	Moorland	42,925t	£2,740,353
	Urban	502,389t	£32,072,526
	Study Area	545,315t	£34,812,878
Carbon Sequestration (per annum)	Moorland	1,340t	£85,515
	Urban	20,498t	£1,308,572
	Study Area	21,837t	£1,394,087
Pollution Removal trees and shrubs (per annum)	Moorland	20.6t	£341,719
	Urban	353.4t	£5,871,354
	Study Area	374t	£6,213,073
Avoided Runoff (per annum)	Moorland	29,025m^3	£44,012
	Urban	491,173m^3	£744,789
	Study Area	520,199m^3	£788,802
Total Annual Benefits	Moorland	£471,246	
	Urban	£7,924,715	
	Study Area	£8,395,962	

Table 1: Headline Figures

Notes on Headline Figures

Total number of trees measured: The random sample inventory figures are estimated by extrapolation from the sample plots. For further details see the methodology section below

Tree Cover: The area of ground covered by leaves when viewed from above (not to be confused with leaf area which is the total surface area of leaves or Canopy cover, Total Canopy Cover and Urban Forest Cover which often also includes the leaf area provided by shrubs)

Potential Plantable Space: Calculated from field measurements and extrapolated from the sample plots

Replacement Cost: 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

Amenity Value: An estimation of the amenity value of Sheffield's trees using a modified Capital Asset Value for Amenity Trees (CAVAT) methodology

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

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

Carbon storage and carbon sequestration values are calculated based on DECC figures of £64 per metric ton for 2017 applied to CO2e, this is the carbon dioxide equivalent, and is a standard unit for measuring carbon footprints.

Pollution removal: This is calculated based on the UK social damage costs and the US externality prices where UK figures are not available; £980 per metric ton (carbon monoxide USEC), £6,528 per metric ton (ozone USEC), £37,879 per metric ton (nitrogen dioxide UKSDC), £1,956 per metric ton (sulphur dioxide UKSDC), £104,627 per metric ton (particulate matter 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 avoided energy and associated greenhouse gas emissions

Capital Asset Value for Amenity Trees (CAVAT): A valuation method with a similar basis to the CTLA Trunk Formula Method, but one developed in the UK to express a tree's relative contribution to public amenity and its prominence in the urban landscape

Data processed using iTree Eco Version 6.1.18 in 2017.

CONTENTS

INTRODUCTION

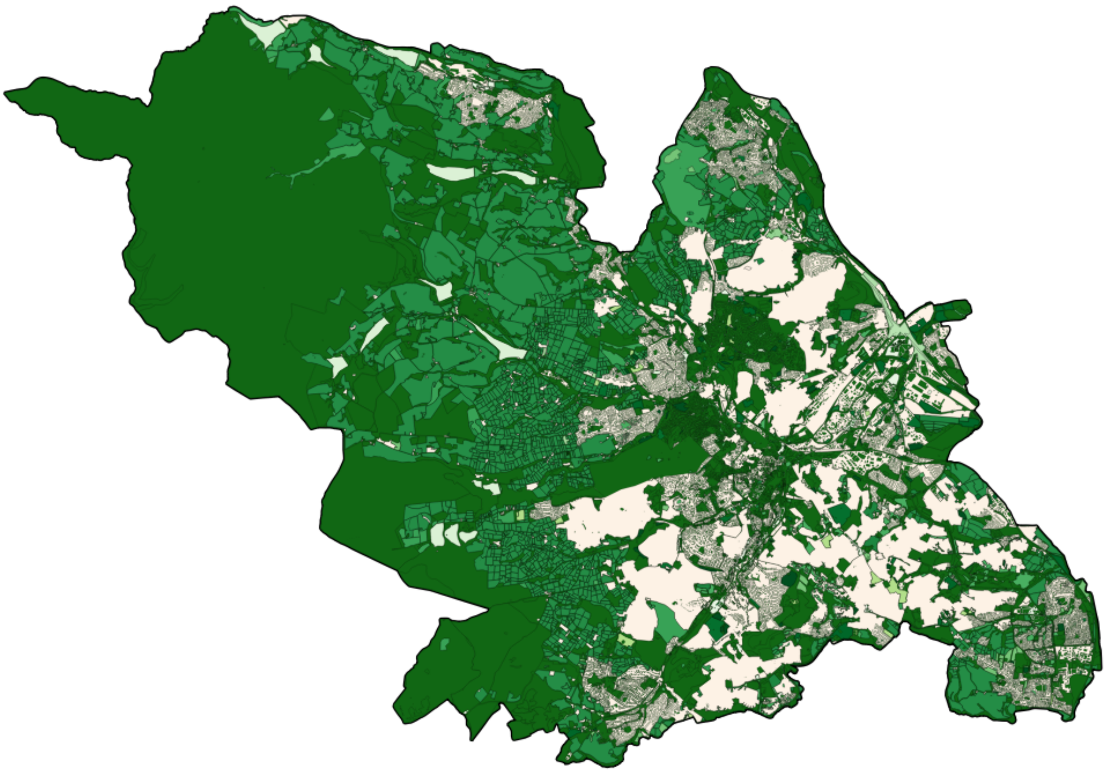

Fig 2. Sheffield's green spaces

The City of Sheffield

Located in the eastern foothills of the Pennines in South Yorkshire, Sheffield is home to 577,800 people[1]. A third of the city of Sheffield lies within the Peak District national park, and as shown by the map above a large proportion of the city is made up of green spaces. In the northwest portion of the city there is a large area of moorland and agricultural land. Within the city there are many green areas including parks, woodlands and gardens. In 2006, Sheffield was described as the greenest city in the UK.

Sheffield's population is projected to increase to 652,300 by 2039. As Sheffield becomes more densely developed and demand for housing increases, the competition for space will inevitably grow, and the urban forest will become an ever more valuable resource. There is a need to protect and manage the established trees in the city, whilst continuing to plant the right trees in the right sites, if Sheffield is to retain its leafy heritage.

[1] The Office for National Statistics, 2017

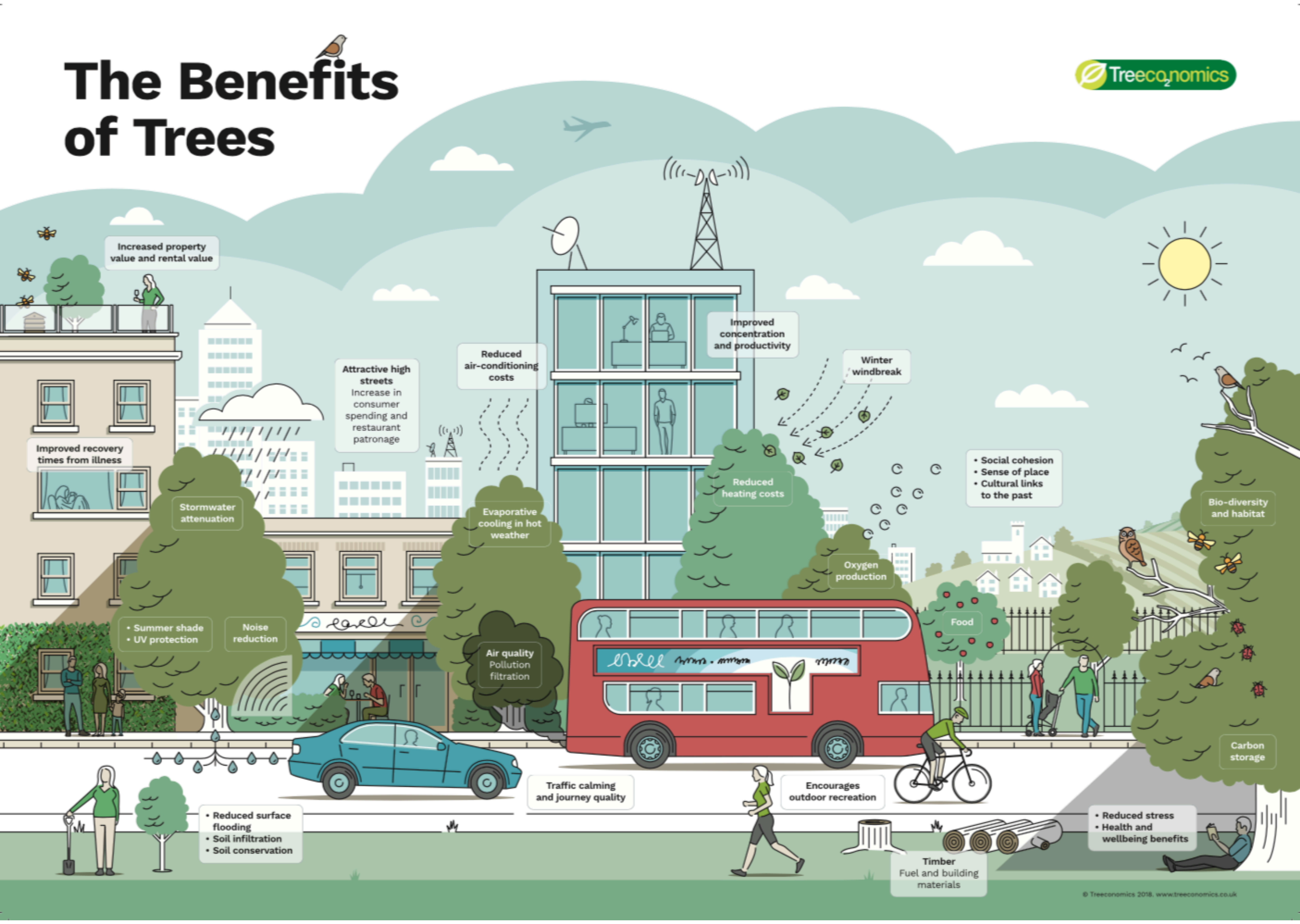

Fig 3: The benefits of trees in the urban setting

The Benefits of Trees

All trees and hedgerows in the urban realm, including those on public and private land, along streets and waterways, in parks, open spaces and woodlands make up the urban forest[2]. Trees in cities bring with them both benefits and costs. Whilst many of the costs are well known, the benefits can be difficult to quantify or justify. Nevertheless, a considerable and expanding body of research exists on the benefits that urban trees provide to those who live and work in our cities, to green infrastructure and to the wider urban ecosystem[3]. Figure 3 above, produced by Treeconomics, describes graphically the many types of benefits trees provide and the challenges they face in the urban realm.

[2] UFWACN (2016)

[3] Wolf (1998)

Aims of the Study

This study has been undertaken in close conjunction with the Sheffield Tree and Woodland Strategy (2018). The iTree project informs and underpins the aims and objectives of the Tree and Woodland Strategy, providing a benchmark against which the composition and future performance of Sheffield's trees can be measured.

Sheffield's Key Aims:

1. Undertake a baseline resource study of Sheffield's trees
2. Increase biosecurity procedures and population resilience to pest and disease across all areas of Sheffield's urban forest
3. Increase the contribution of Sheffield's urban forest to addressing air pollution
4. Raise awareness of the importance of Sheffield's urban forest to increase public engagement and understanding
5. To provide information to assist the strategic future tree planting programme

Project Key Aims and Objectives:

Over-arching project aim:

1. To develop an evidence base to inform the strategic approach to urban forest management (the Tree and Woodland Strategy)

Project objectives:

1. To provide values on the contributions of the trees and woodlands of Sheffield to air quality;
2. To provide values on the contribution of Sheffield's trees and woodlands to carbon sequestration and storage;
3. To provide values on the contribution of Sheffield's trees and woodlands to stormwater attenuation;
4. To provide values on the amenity of Sheffield's trees and woodlands as calculated by the CAVAT system

METHOD

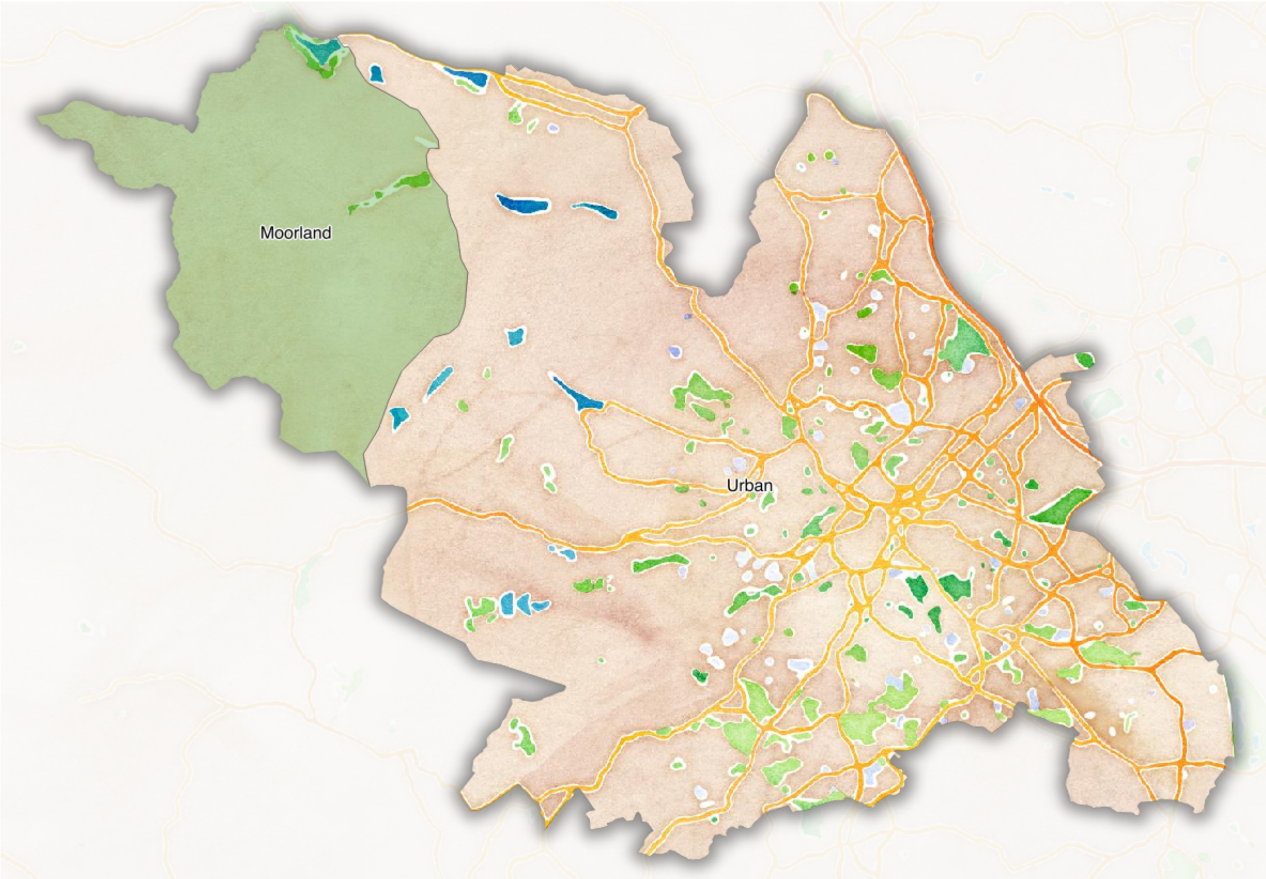

Fig 4: Moorland and Urban areas in Sheffield

To gather a collective representation of Sheffield's urban forest across both public and privately held land an i-Tree Eco (v6) plot-based assessment was undertaken. 261 randomly allocated plots of 0.04ha (400m^2) were surveyed, representing 0.03% of the total survey area (of 36,795ha). This equates to 1 plot every 141ha.

261 plots allowed for the eventuality that up to 20 plots may be inaccessible whilst still maintaining a statistically robust estimate of the study area. Fortunately, almost all of the target 261 plots were accessible and those that were not accessible were visible, thus allowing the estimation of tree attributes to be undertaken. All 261 plots were therefore able to be inventoried.

The study area was stratified to take account of the large area of moorland which makes up a large proportion of Sheffield's political boundary (Fig 4.). Because the area of moorland (6865 ha) is largely uniform, 27 plots were allocated to this strata (1 plot every 254ha). The urban strata (29,930ha), which has much greater variation in ground cover was allocated 234 plots (1 plot every 130ha).

Random plot selection, generated using GIS software ensures that trees on both public and private land are included in the assessment. The information collected for each plot is detailed in table 2, below.

Plot information	Land use, ground cover, % tree cover, % shrub cover, % plantable space, % impermeable surface.
Tree information	Tree species, height in (m), trunk diameter at breast height (dbh), canopy spread, the health and density (or fullness) of the canopy, light exposure to the crown.

Table 2. Field Data

This data was collected by trained volunteers and arboricultural professionals during the summer of 2017. Using i-Tree Eco the field data were combined with local climate and air pollution data to produce estimates of the urban forest structure and the benefits or ecosystem services provided by trees. The full list of outputs generated is shown in table 3, below.

Urban Forest Tree Structure and Composition	Leaf area and canopy cover, % leaf area by species. Age class, size class, tree condition. Species diversity, species dominance. Urban ground cover types.
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 but the figures are included in the report.
Ecosystem Services	Replacement Cost in £. Carbon storage value in £. Carbon sequestration value in £. Pollution removal value in £. Avoided runoff in £.
Pest and disease impacts	Ash Dieback Ramorum Disease Asian LongHorn Beetle

Table 3. Study outputs

For further technical information on the methodology used see Appendix I or refer to the documentation available at www.itreetools.org

Data limitations

The benefits of Sheffield's trees are highly valuable. However, the values presented in this study represent only a portion of the total value of the trees within Sheffield as it is not possible to place a pound value on all of the benefits trees provide. For example, i-Tree Eco does not currently value the role of trees in moderating local air temperatures, in reducing noise pollution and improving health and well-being, providing wildlife habitat and, even, the ability to unite communities. Hence, the value of the ecosystem services provided in this report are a conservative estimate.

Furthermore, the methodology has been devised to provide a statistically reliable representation of Sheffield's urban forest in 2017. Whilst this report has been devised to collect information on trees and shrubs within the survey plots, it should be used only for generalised information on the urban forest structure, function and value. Where detailed information for a specific area (such as an individual park, street or ward) is needed, further survey work would be required.

RESULTS AND ANALYSIS

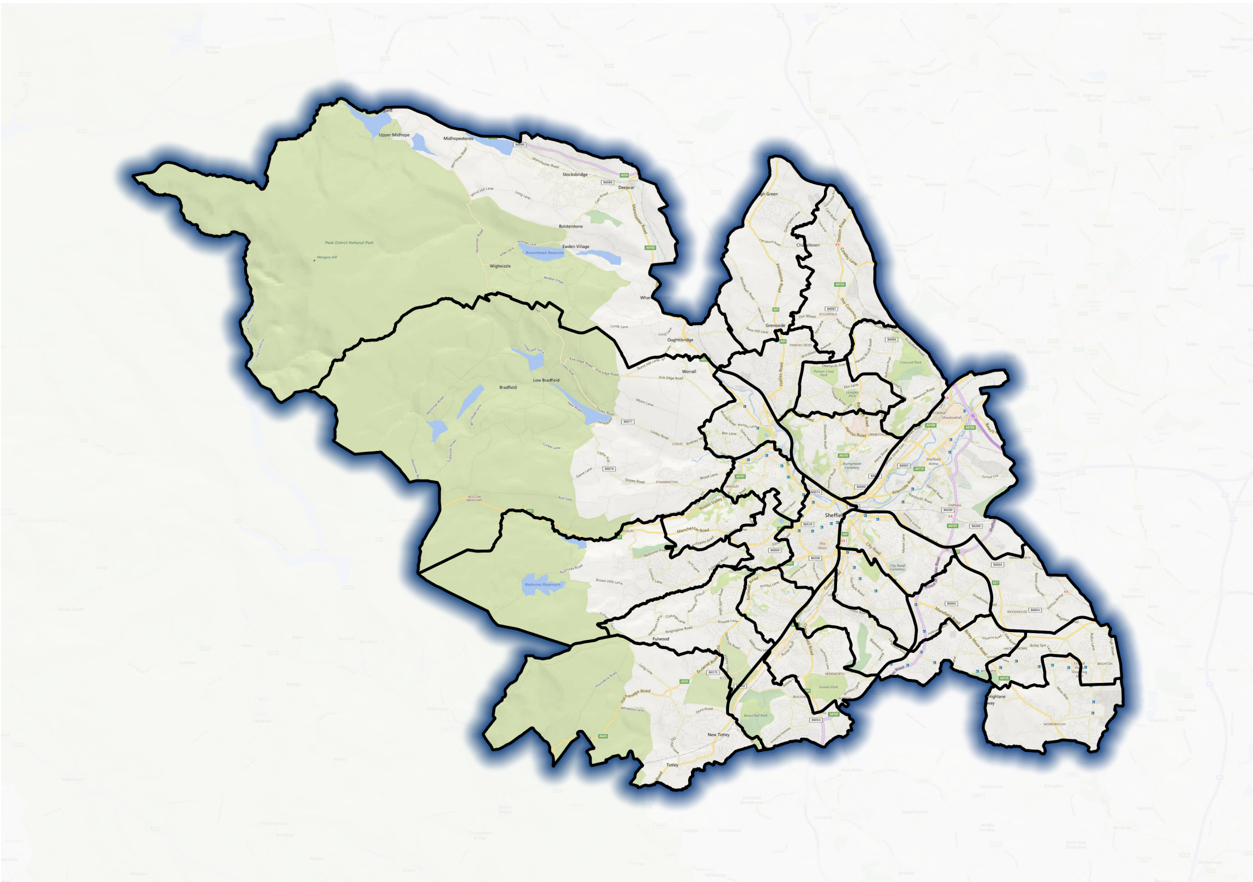

Fig 5: Sheffield's administrative areas

Structure and Composition

Land use and Ground Cover

Ground cover in Sheffield (as measured using i-Tree Eco) was stratified across two land-uses; 'Urban' and 'Moorland' (figure 4, above). The urban area totalled 29,930ha and the moorland area 6,865ha. Tree cover was estimated at 21.6% for the plots surveyed in the urban area and 4.6% across the moorland plots. Across the entire Sheffield study area, tree cover is estimated at 18.4%.

Ground Cover - Urban

The urban realm consisted of approximately 60% permeable ‘green space’, such as grass, annual and perennial herbaceous plant cover. In addition, 14.4% of ground-cover across urban areas was classified as ‘bare soil’. 24.4% of ground-cover consisted of impermeable surfaces (the ‘built environment’ and a small proportion of bare rock surfaces). Compare this with the London Borough of Ealing iTree Eco study where the ground-cover of over 50% of the plots surveyed consisted of impermeable surfaces.

Ground Cover - Moorland

In comparison with the urban realm, the ground cover of the moorland region of the Sheffield study area comprised a less complex make-up. 100% of the plots surveyed across this area were classified as being used for agriculture with most of this being heather-covered moorland. 24% of the area comprised unmaintained grass (native grasses amongst the heather) and just over 6% as annual and perennial herbaceous plant cover.

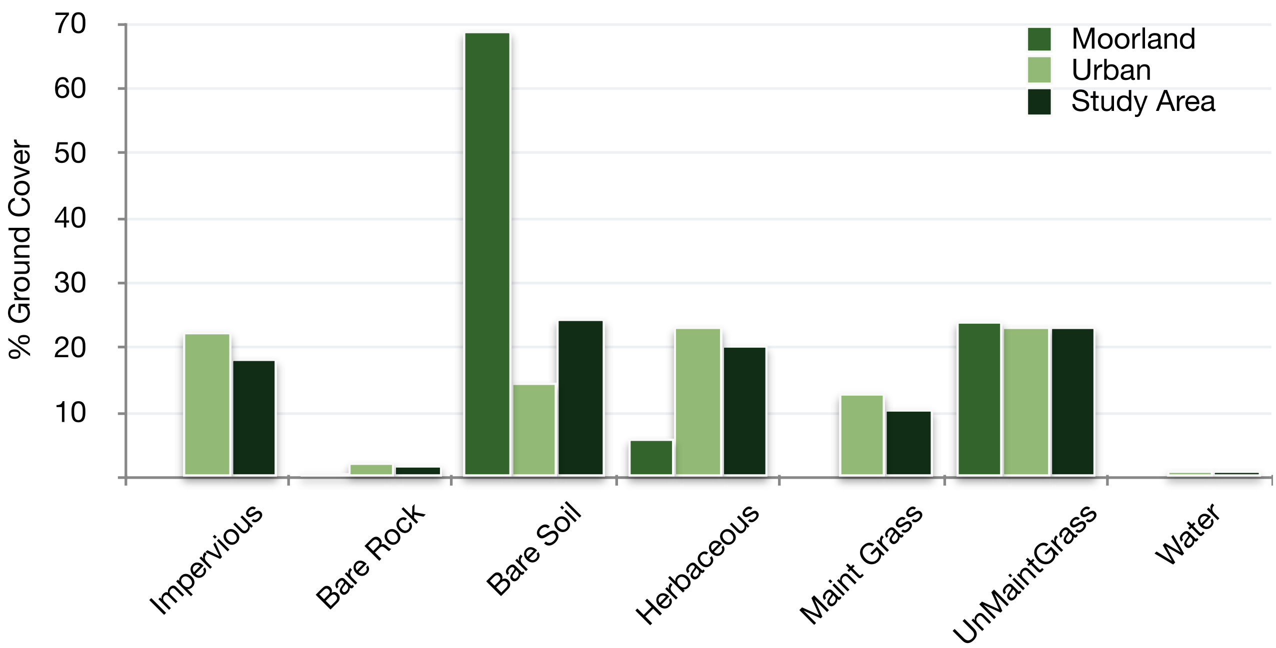

Fig 6. Ground cover by stratum for the study area of Sheffield

"Across Sheffield there are an estimated 3,863,630 trees over 7cm stem diameter"

Tree Population

Across Sheffield there are an estimated 3,863,630 trees over 7cm stem diameter. The trees that make up this urban forest are situated on both public and private property. Across the moorland area, 100% of the area within the plots surveyed was within private ownership (though most is open access moorland). This is to be expected as all the plots surveyed were situated on privately owned moorland. Across the whole survey area (moorland and urban) the i-Tree Eco data estimates that around 60.4% of trees are in public ownership and 39.6% in private ownership.

For illustration, the public/private split calculated with i-Tree Eco for Greater London was 43% public and 57% private ownership. Across the UK, US and Europe the average public: private split is around 40%-60% to 30%-70%[4].

Tree density across Sheffield is 105 trees per hectare (126 trees/ha urban,12.8 trees/ha moorland). This is significantly higher than the average density of trees across London (53 trees/ha)[5] and the current UK average for towns and cities (58 trees/ha)[6]. Roughly speaking this equates to around 7 trees per person across the Sheffield study area (for the London i-Tree Eco study, the figure calculated was 1 tree per person). However, the precise geographical

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[4] Brit and Johnston (2008), Nowak (2000).

[5] Rogers et al (2015)

[6] Britt and Johnstone (2008)

distribution of these trees across the city (which is another important consideration regarding access to the benefits trees provide) is beyond the scope of this report.

Canopy Cover

Canopy cover is the area covered by trees when looked at from above. Leaf area (discussed later) is the total area of all the leaves which are layered throughout a tree canopy.

Canopy cover, which is often also referred to as tree canopy cover and urban tree cover can be defined as the area of leaves, branches, and stems of trees covering the ground when viewed from above.

At 18.4% across the whole study area (and as much as 21.6% for the urban part of the study area), canopy cover for Sheffield compares favourably with other towns and cities[7]. Table 4, below shows selected results from studies across different urban areas of the UK from the Urban Tree Cover website[8].

City/District	% Tree cover	Source
Birmingham	23.00	i-Tree Canopy Survey 2012
Exeter	23.00	i-Tree Canopy Survey 2013
London	21.90	i-Tree Eco Project 2015
Oxford	21.40	i-Tree Canopy Survey 2015
Plymouth	18.50	i-Tree Canopy Survey 2017
Sheffield	18.40	i-Tree Eco Project 2017
Newcastle	18.10	i-Tree Canopy Survey 2018
Walsall	17.30	i-Tree Canopy Survey 2012
Edinburgh	17.00	i-Tree Survey 2012
Wrexham	17.00	i-Tree Survey 2014
Ealing	16.90	i-Tree Survey 2018
Eastbourne	15.90	i-Tree Canopy Survey 2011
Manchester	15.50	Red Rose Forest survey 2007
Glasgow	15.00	i-Tree Survey 2014
Bristol	14.00	Bristol Tree Survey 2009
Telford	12.50	i-Tree Canopy Survey 2012
Torbay	12.00	i-Tree Survey 2011

Table 4. Tree cover in Sheffield

"Tree Cover in Sheffield is 18.4%, Whilst 60% of Sheffield is made up of green space"

[7] Total canopy cover (including shrubs) for Urban Sheffield is 36.6%

[8] www.urbantreecover.org. Where i-Tree Canopy figures are stated the total may also include shrubs

Tree Species Composition

Tree species composition is an extremely important metric to consider for the sustainable management of the urban forest.

An urban forest that possesses a diverse species composition can improve the aesthetic value and amenity of a space or locality. It will also improve the resilience of the urban forest to the combined threats of novel pests and diseases and of a changing climate. A high level of in-built resilience within the urban forest population in terms of species diversity would help to limit the impact of any perturbations to the trees of Sheffield. This increased resilience would, in turn, limit the disruption to ecosystem service provision.

In total, 68 tree species were recorded in the survey.

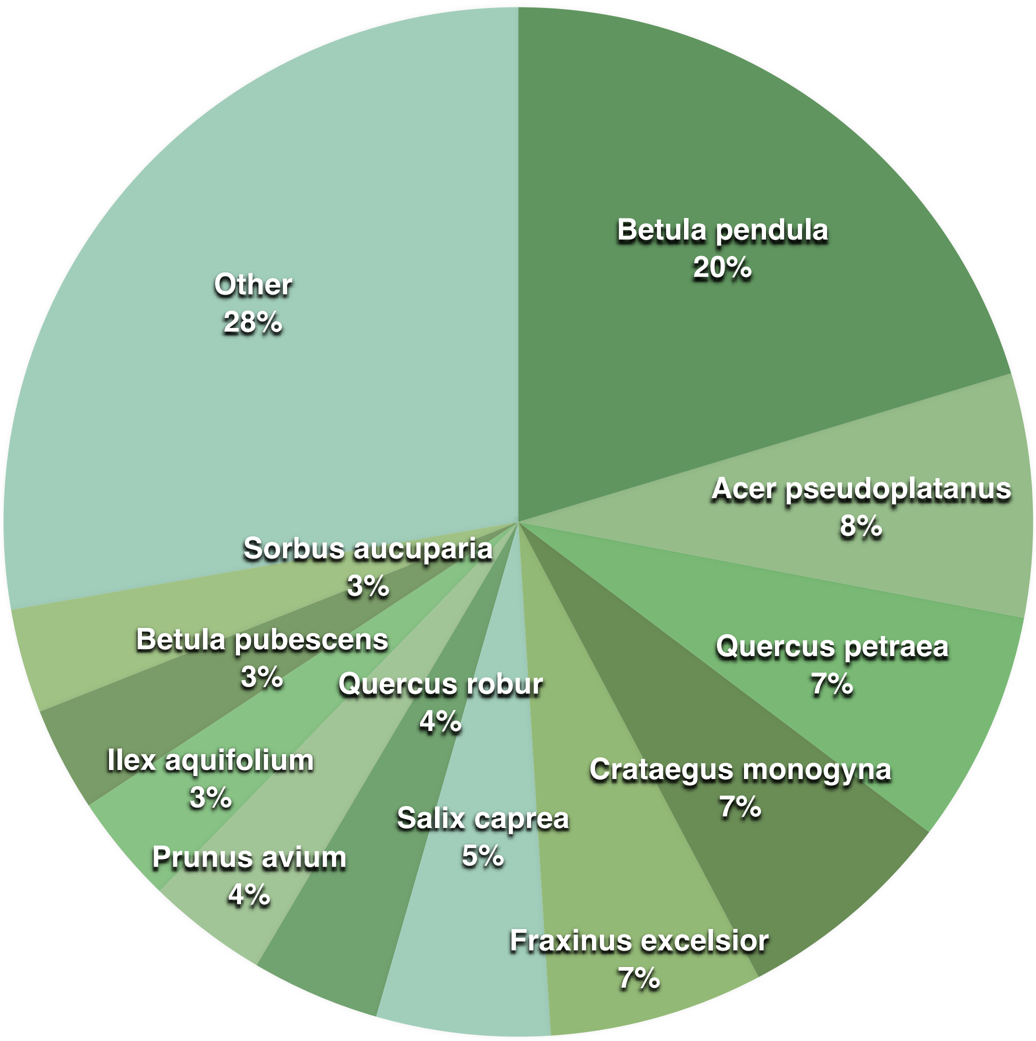


Fig 7. Tree Species Composition

It is worth noting that as a sample survey the total number of species recorded is very likely not the absolute number of species that would be found across Sheffield. The very nature of a sample survey means that only a fraction of the urban tree population is captured.

The sample survey, however does provide a good estimate of the most frequently encountered species across Sheffield.

The three most common genera of trees across Sheffield are Birches (Betula) with an estimated 945,002 trees (24%), Oaks (Quercus) with 453,464 trees (12%) and Maples (Acer) with 336,320 trees (9%). Table 5 (below) lists the top ten genera.

Genera	Est Population
Betula	945,002
Quercus	453,464
Acer	336,320
Crataegus	298,121
Fraxinus	272,863
Pinus	257,000
Salix	225,270
Prunus	168,159
Sorbus	139,604
Ilex	130,086

"In Sheffield the top ten genera account for 83% of the total population"

Table 5. Top ten genera across Sheffield

By way of comparison, the three most common species found across Greater London were sycamore (Acer Pseudoplatanus) with 7.8% of the population, English oak (Quercus robur) at 7.3%, and silver birch (Betula pendula) at 6.2%.

Reviewing the species composition across both the public and private landholding within Sheffield allows for planned public planting to compliment and enhance the private tree stock. This ensures that there is not over-reliance on a single species or genera, for example. Planting on the private estate is also more difficult to influence and so a knowledge of what the overall tree species composition is can help in selecting or suggesting species when advice is sought.

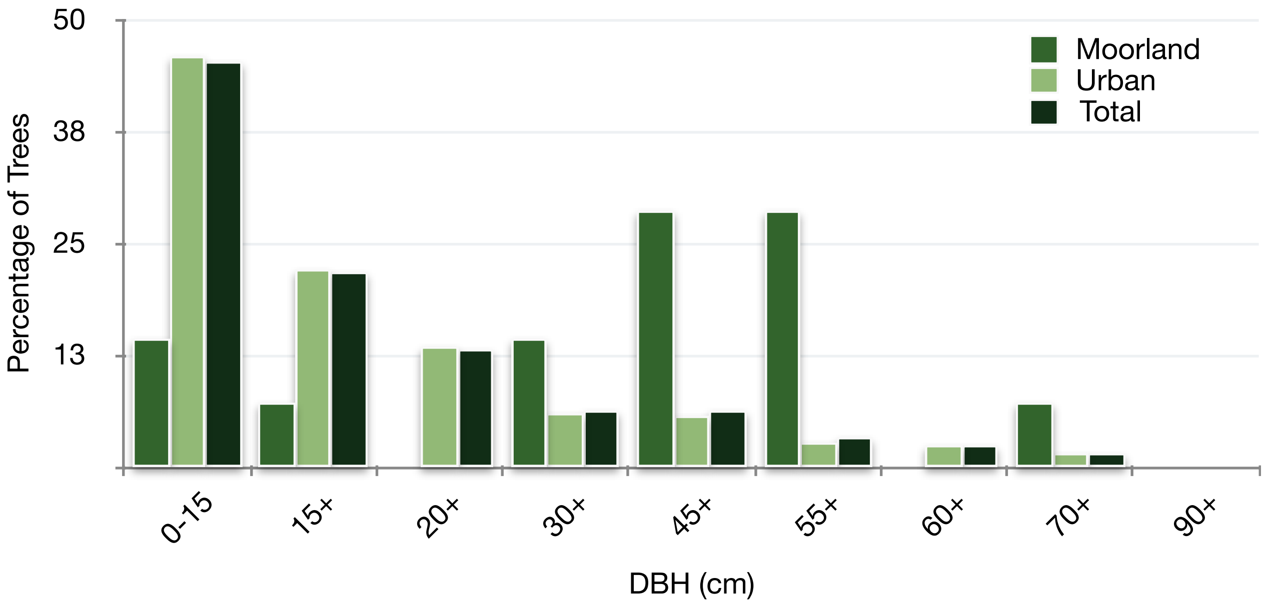
Tree Size Distribution

The size distribution of trees is another important consideration in managing a sustainable and resilient 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.

Large, mature trees offer unique ecological roles and provide a greater proportion of tree benefits that far exceed the contributions of small trees[9]. However, young trees are also needed to restock the urban population as older trees die and trees need to be planted in a surplus to allow for mortality or removal.

Figure 8 (below) illustrates the dbh size range of trees across Sheffield.

Fig 8. Size class distribution



Trees with a dbh equal to or less than 15.2cm account for 45.3% percent of the population across the entire Sheffield survey area (46% across the urban land-use and 14.3% for trees inventoried across the moorland). By way of comparison, across London the average composition as revealed by the iTree Eco inventory was 35% for trees below 15.2cm stem diameter (42% for Inner London and 34% in Outer London).

The majority of trees across Sheffield are within the smallest size categories, with around 80% of the trees recorded having a stem diameter of less than 30.5cm. Across the two land-use strata, the picture changes; the urban inventory finding 81.6% of trees had a stem diameter of 30.5cm or less and the moorland land-use just 21.4% for the same category. Some caution should be

[9] Lindenmayer et al. (2012)

exercised here, however due to the small sample size for trees inventoried across the Moorland land-use and the relatively high standard error as a result when extrapolating across the area.

The survey results for Sheffield reflect those of other cities and towns in England where the Trees in Towns 2 survey found that on average only 10-20% of trees have a stem diameter that is greater than 30 cm.

Trees in the 84-92cm stem diameter class represent the smallest category by number across the survey area. Just 0.01% of the total population is represented in this category, and just 20% of all trees measured bearing a stem diameter of 30.5cm or more. To maintain a level of mature larger trees, equal to the current stocking of trees with a stem diameter greater than 70cm, a proactive approach will be required to manage the trees currently in the 30-50cm stem diameter category to ensure a suitable proportion of these trees survive and thrive to attain larger sizes.

Large, mature trees occupy a unique cultural and ecological niche, offering features which simply cannot be replicated by trees of smaller stature. Careful management of the entire urban forest, not to mention placement of potentially large specimens is required in order to ensure tree performance and thus ecosystem service provision is maximised. Similar to other studies, a greater proportion of larger trees would benefit the size diversity of Sheffield's urban forest.

"The first step in re-incorporating green infrastructure into a community's planning framework is to measure urban forest canopy and set canopy goals". James Schwab

Leaf Area and Dominance

Whilst tree population statistics give a very useful insight into the composition of the urban forest, when combined with measurements on leaf area a greater understanding of the dominance that different species play in the delivery of benefits within the urban forest is obtained. Leaf area is the total area of all the leaves which are layered throughout a tree canopy and is therefore different from canopy cover, varying with species characteristics, condition and previous management.

A high dominance value does not necessarily imply that a particular species should be preferred in any future planting strategy. However, it does show which species currently deliver the most benefits based on population and leaf area.

The main benefits derived from trees are directly linked to the amount of healthy leaf surface area that they possess. To demonstrate the dominance of a species, the total estimated leaf surface area for that species as a percentage of the total, combined with its abundance in the overall population (also as a percentage of the total), indicates its relative contribution of benefits. This is termed the dominance value (DV).

Taking into account the leaf area and relative abundance of the species, i-Tree Eco calculates the DV for each species, ranking the trees in respect of their dominance for the delivery of benefits or ecosystem services. As Table 6 (below) shows, the most dominant species varies from the most prevalent species by population.

Species	% Population	% Leaf Area	Dominance Value
Betula pendula	21.2	17.4	38.6
Acer pseudoplatanus	7.5	14.7	22.2
Quercus petraea	7.8	12.0	19.8
Crataegus monogyna	7.1	4.6	11.7
Fraxinus excelsior	6.6	4.9	11.5
Salix caprea	5.3	4.4	9.7
Prunus avium	3.7	4.4	8.1
Quercus robur	3.9	3.4	7.3
Fagus sylvatica	3.1	2.7	5.8

Table 6: Ten most dominant tree species in Sheffield

Figure 9 shows the composition of trees by leaf area. Across Sheffield, the top three tree species are silver birch (Betula pendula), sycamore (Acer pseudoplatanus) and sessile oak (Quercus petraea). These three species are also the most populous trees within the survey (with 21.2%, 7.5% and 7.8% of the population respectively). Silver birch is over two and a half times more prevalent than the second most populous species (sessile oak) but the leaf area is just 1.2 times that of the species with the second highest leaf area (the sycamore). This highlights the smaller average canopy size of silver birch tree included within the inventory, by virtue of the morphology of the species in terms of crown structure and leaf size, but also the short-lived nature of the genus Betula. It also shows the importance of incorporating larger growing tree species in the urban forest which will deliver more significant benefits over longer periods of time.

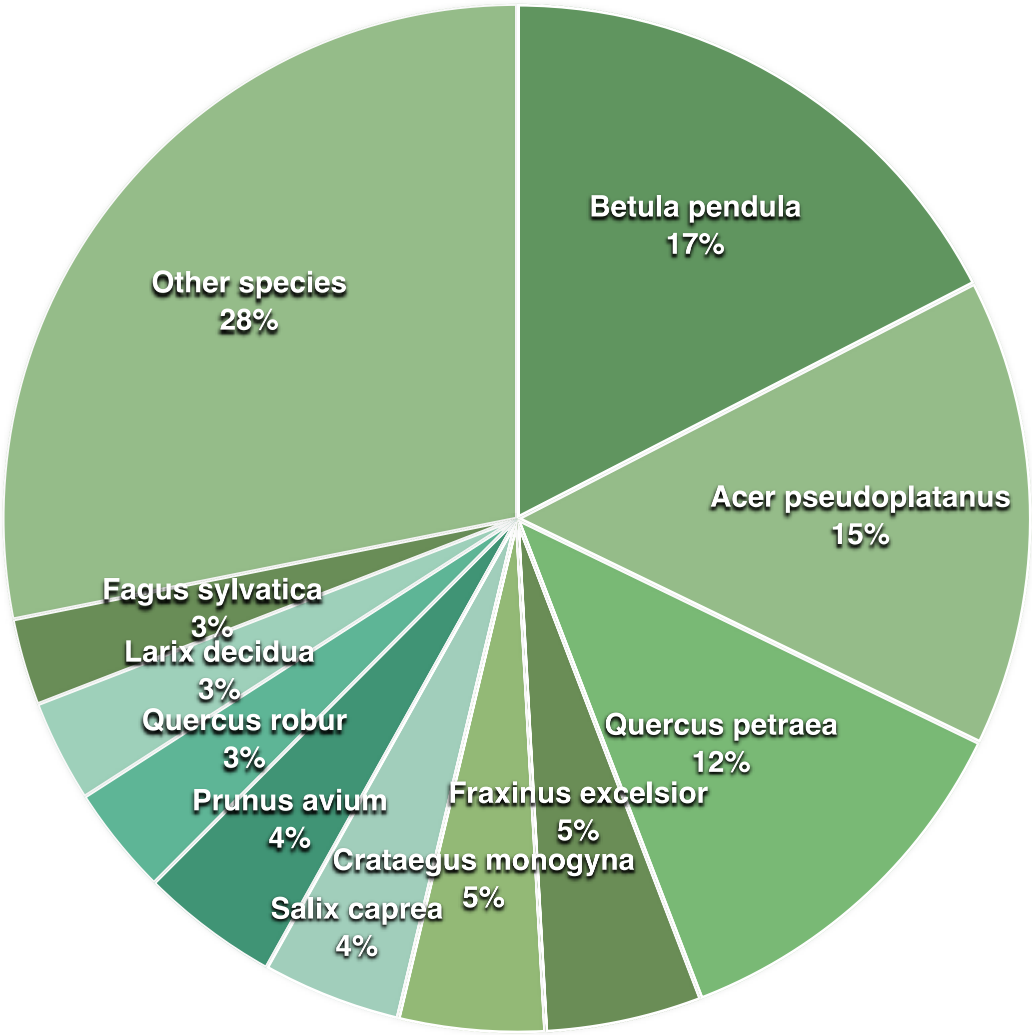


Fig 9: Leaf area by species

The species identified in Table 6 currently dominate the urban forest structure. Their continued health and performance is therefore important in delivering ecosystem services. However, future planting programmes should also take into account issues such as climate change, pests and diseases and the likely built form of neighbourhoods, streets and new developments. Delivering a sustainable urban forest with an increasing or at least stable level of healthy canopy cover is a complex process requiring integration of a number of disciplines, most appropriately through an urban forest masterplan.

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

Overall, the total leaf area provided by Sheffield's trees is over 23,300 ha. This equates to over 63% of the total surface area of Sheffield. As figure 9 (above) shows, the top ten tree species provide 72% of the total leaf area of Sheffield and the top three 34%. This indicates a fairly heavy reliance on a small number of species to deliver over a third of the ecosystem services for Sheffield.

10 Every Tree Counts: A Portrait of Toronto's Urban Forest https://www.itreetools.org/resources/reports/Toronto_Every_Tree_Counts.pdf

Tree Diversity

As stated previously, a total of 68 tree species were recorded across Sheffield. All 68 species were recorded in the urban stratum and just 3 across the moorland (by comparison there are around 50 native tree species in the UK)[11].

Diversity in the urban forest has two main components, the number of species present and the genetic diversity of the individual species present. This diversity reduces the potential impact from threats such as new pests and diseases and climate change and increases the capacity of the tree population to deliver ecosystem services. The diversity of species will influence how resilient the tree population will be to future change.

Figure 10 (overleaf) shows the origin of tree species across the Sheffield study area, stratified into the two land uses (urban and moorland). This information is useful in providing an additional indication of the resilience or susceptibility of the urban forest. For example, knowing the origin of imported pests and diseases will give an indication of which tree species have co-evolved with them and may thus have developed a natural resistance or even immunity to them.

11 https://www.woodlandtrust.org.uk/visiting-woods/trees-woods-and-wildlife/british-trees/native-trees/

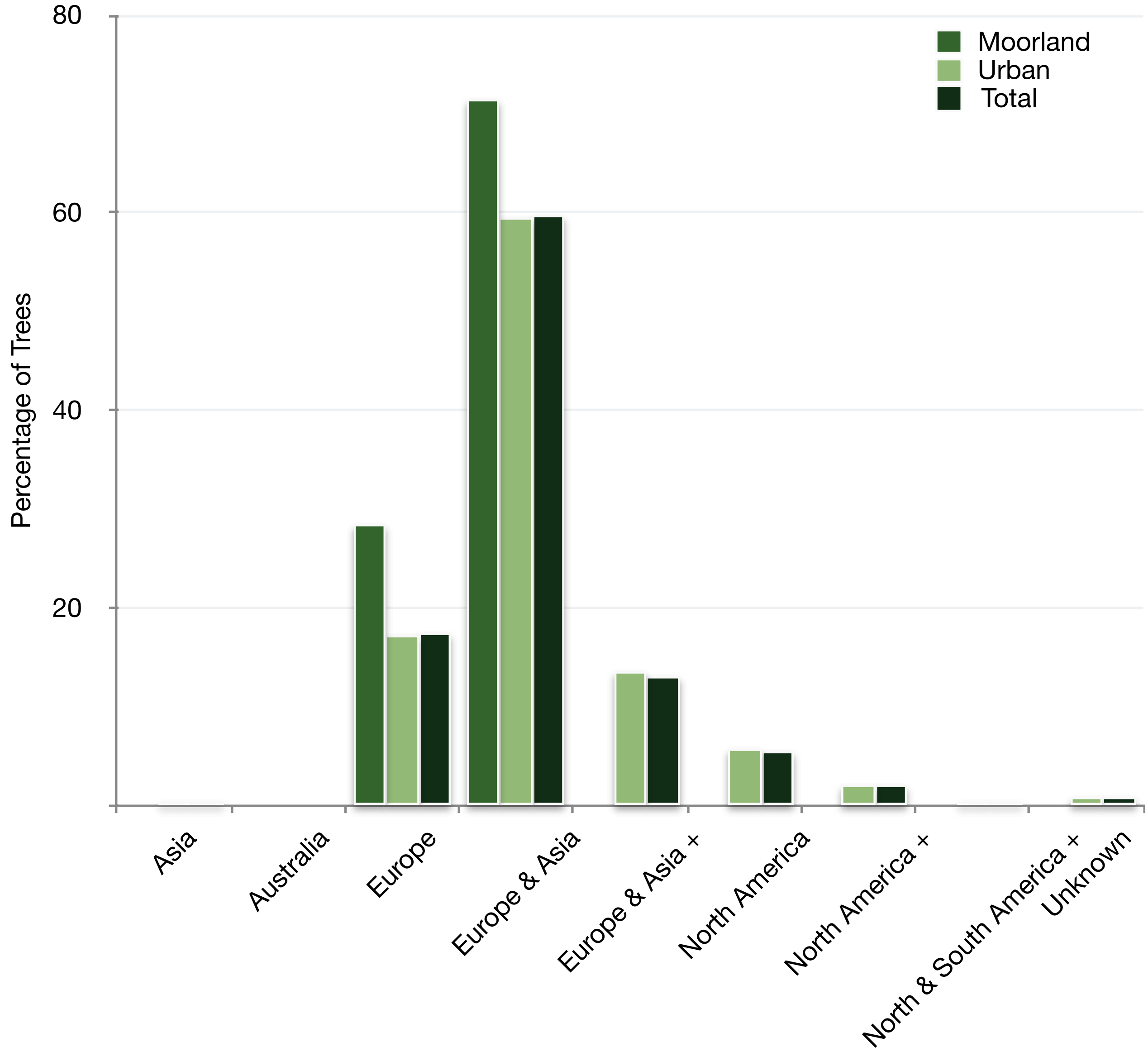


Fig 10: Species origin

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

Structure and Composition

Recommendations

The diversity of tree species across the urban stratum of the Sheffield study area is generally good, with 68 species recorded. However, improving diversity, in-particular at the genus and family level would potentially improve resilience to a wide variety of perturbations which may have an adverse impact on the population.

Birches are the most common species and genus across Sheffield and with the oaks and the maples provide the bulk of the benefits. However, this level of dominance across an area does indicate a heavy reliance on a small number of species to deliver ecosystem services. If, for instance, the impact of climate change produces a warmer local climate, or a change in precipitation patterns, the pathogenicity of a disease (for instance sooty bark disease of sycamore, *Cryptostroma corticale*) may increase, thus leading to an increase in the mortality rate of this species.

Tree density across Sheffield (trees per hectare) is significantly higher than the UK average and the average recorded across other studies. However, the precise distribution across the study area and a more accurate indication of the access for local residents to the benefits trees provide is beyond the scope of this report.

There is a disproportionate amount of smaller stature trees to larger trees across Sheffield, although the range is typical for that calculated across the urban areas of England. Larger trees (those over 60cm dbh) provide great benefits and return on investment.

Leaf area and population composition are easy to measure, and give a better indication of relative tree presence or dominance than just numbers of trees alone because it incorporates the area of leaves in the tree canopies, which are the driving force of many tree benefits.

Therefore it is recommended that:

1. A wider variety of tree species are planted (with due consideration to local site factors) to reduce the likelihood and impact from any given pest or disease outbreak or change in climate.

2. Protection for existing mature and maturing trees is enhanced, together with increasing the planting of large-stature trees, (where possible) to increase canopy cover and the provision of benefits. Reviewing existing Tree Preservation Orders and making new ones as

appropriate is recommended. This should be targeted to those wards with the least tree cover at present.

3. Sheffield should calculate canopy cover at the ward level, undertaking a desktop analysis using aerial imagery to do so. This, coupled with the results of the Eco study, will enable the setting of a canopy cover goal to increase tree canopy cover on both public and private land. A suggested goal might be to develop a strategic planting plan to achieve an average canopy cover target of 20% over next 20 years. Part of this goal can be achieved by protecting and growing existing trees (see 2 above). It might be more appropriate to make ward specific canopy targets as a more targeted approach, taking into consideration local factors.

4. In order to implement and monitor these recommendations, and those that follow in further sections, it is also recommended that:

- **i. A systematic inventory of all trees which come under Council ownership is carried out. The inventory would include species, tree dimensions and condition criteria. This could be a rolling inventory, incorporated as part of ongoing tree risk assessment inspections the Council already undertakes**

- **ii. an online webmap or dashboard is produced to display the current data and future changes**

- **iii Sheffield City Council has recently (2018) produced and adopted a Tree and Woodland Strategy (TWS). The following recommendations should be considered and actioned as part of the next annual review of the TWS:**

    1. **Describe the nature and extent of the urban forest and provide a vision that is needed in the future, together with an action plan for delivery and monitoring;**

    2. **Set individual canopy cover targets for key land uses and/or geographic areas as Key Performance Indicators which is integral to the delivery of the Local Plan;**

    3. **Set ambitious targets for cooperative development of the Urban Forest with communities, local business, utility companies and so on;**

    4. **Monitor canopy cover as a Key Performance Indicator for management of the urban forest, including the monitoring of numbers of trees removed and trees planted;**

5. **Identify and prioritise actions through planting and management to ensure that tree cover is maintained, sustained and improved where this is appropriate;**

6. **Describe the role of trees within the landscape setting of Sheffield;**

7. **Develop a set of principles, standards, policies and constraints relating to trees that can be used to guide the design, development, deployment and operation of services delivered by trees in the city of Sheffield.**

8. **It will also set out criteria for a repeat assessment over an agreed timeframe to monitor progress.**

5. **Further investigation needs to establish if there are any barriers to the planting and establishment of trees in the lowest performing wards. This could be integrated into 4. iii above.**

Ecosystem Services

Air Pollution Removal

Air pollution caused by human activity has become a growing albeit changing problem in our urban areas since the beginning of the industrial revolution. Initially with the increase in population and industrialisation, and latterly with the huge increase in the numbers of vehicles on our streets, it has resulted in large quantities of pollutants being produced.

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

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

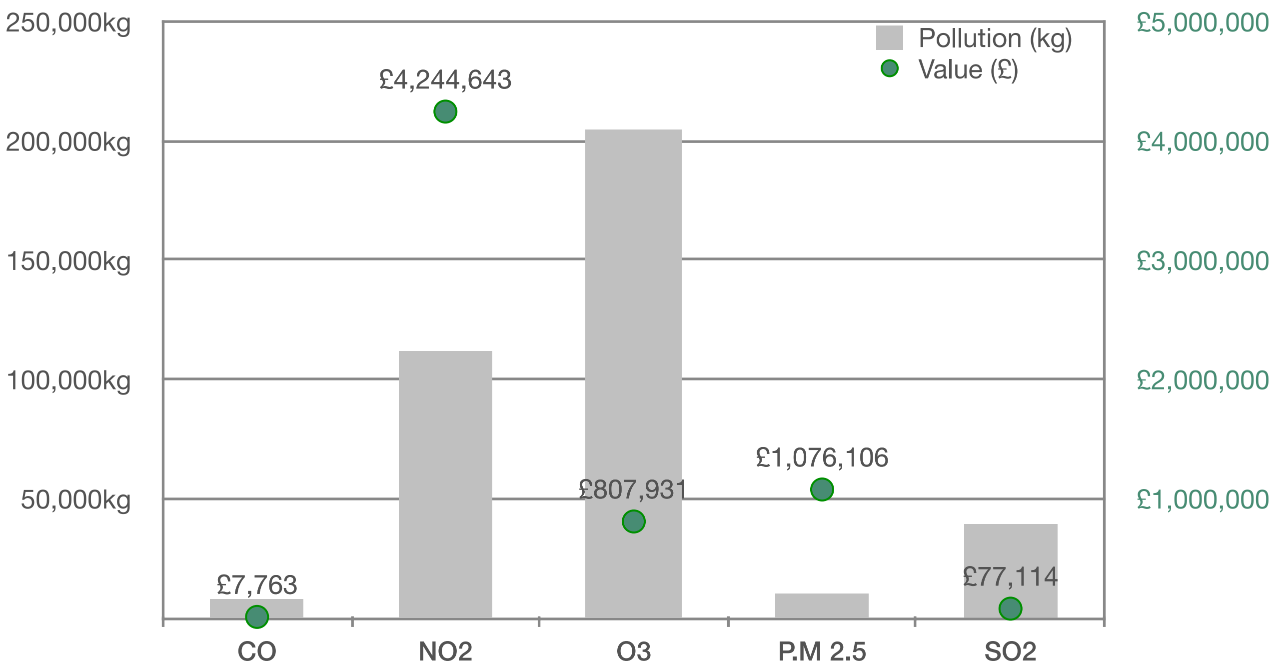


Fig 11: Value of the pollutants removed and quantity per-annum within Sheffield. Valuation methods used are UK social damage cost (UKSDC) where they are available - where there are no UK figures, the US externality cost (USEC) is used as a substitution.

As well as reducing ozone levels[12], it is well known that a number of tree species also produce the volatile organic compounds (VOCs) that lead to ozone production in the atmosphere. The i-Tree software accounts for both reduction and production of VOCs within its algorithms. Although at a site specific level some trees may cause issues, the overall effect of Sheffield's trees is to reduce the production of ozone through a combination of processes such as evaporative cooling.

Total pollution removal across Sheffield (i-Tree Eco sample survey of both trees and shrubs) is estimated at 374 tonnes or 0.01 t/ha/yr (10kg/ha/yr). This value is significant and for comparison the recorded average for pollution removal for Greater London was 0.014 t/ha/yr, Glasgow 0.050t/ha/yr and Torbay 0.0078 t/ha/yr[13].

Total annual amounts and pollution removal values for Sheffield are shown in Figure 11 (above). By quantity, removal of Ozone (O_3 - formed by the action of sunlight on nitrogen dioxide) is greatest by quantity, with over 204 tonnes filtered from the air every year and an associated value of over £800,000 every year. By total value, the work done by trees and shrubs to remove nitrogen dioxide (NO_2) is greatest, worth over £4.2 Million. However, by unit value, the work done by trees and shrubs to remove small particulate matter ($PM_{2.5}$) proves to be of greatest benefit, worth £104.63 per kg (a total value of over £1 Million from over 10.2 metric tons of particulate matter removal).

Greater tree cover, pollution concentrations and leaf area are the main factors influencing pollution filtration. 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 canopies that provide the most benefits.

[12] Nowak and Dwyer (2000)

[13] Rogers et al 2015

Carbon Storage and Sequestration

Trees have a significant influence on the balance of carbon in the atmosphere, sequestering atmospheric carbon as they grow as part of the carbon cycle. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots can store carbon for decades or even centuries. Over the lifetime of a single tree, several tons of atmospheric carbon dioxide can be absorbed.

Carbon storage relates to the carbon currently held in trees tissue (roots, stem, and branches), whereas carbon sequestration is the estimated amount of carbon removed from the atmosphere in carbon dioxide (CO_2) annually by trees. Net carbon sequestration can be negative if the emission of carbon from decomposition (dead trees) is greater than the amount sequestered by healthy trees.

Maintaining a healthy tree population will ensure that more carbon is stored than released[14]. 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.

An estimated 545,314 tonnes (approximately 14.8t/ha) of carbon is stored in Sheffield's trees with an estimated value of £34.8 million. Approximately 43,000 metric tons are stored in the moorland stratum trees and 502,400 metric tons in the urban stratum. For comparison, across London carbon storage is around 15t/ha on average, Sheffield therefore compares quite favourably with the nation’s capital in this regard.

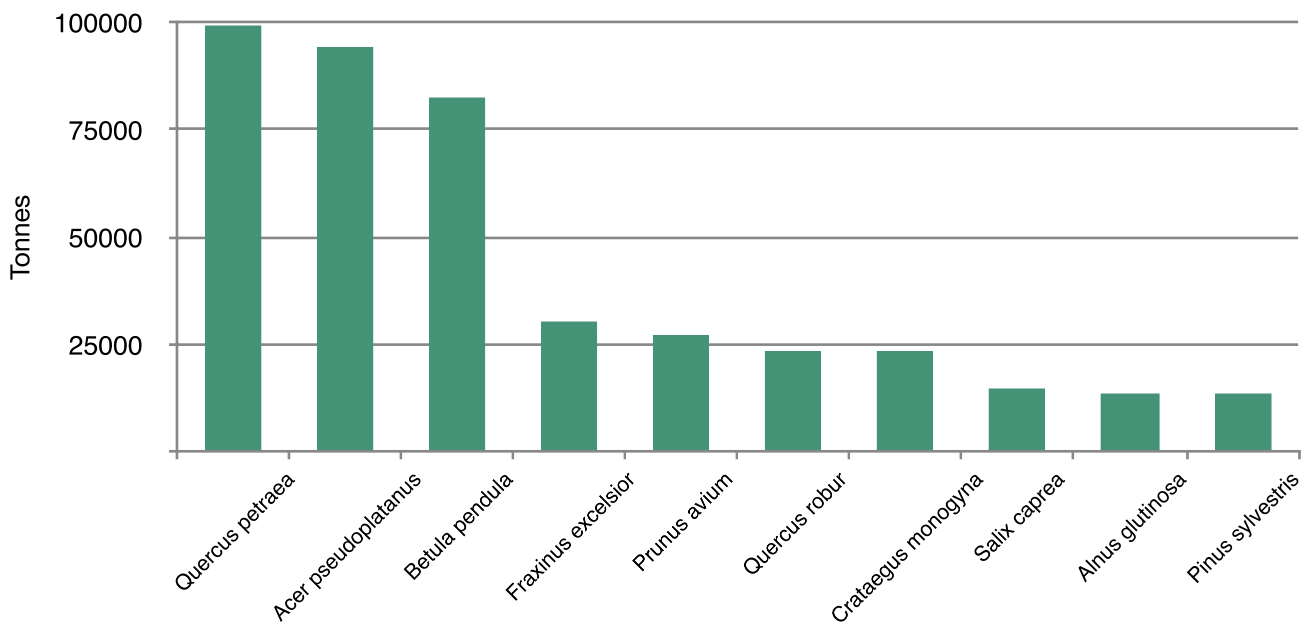


Fig 12: Ten most significant tree species across Sheffield and the associated carbon storage.

[14] Nowak et al (2002c)

As figures 12 and 13 show, there is quite a heavy reliance on the top ten tree species to store and sequester the majority of carbon (425,345 metric tons, 78% of the total) with the top three tree species (sessile oak, sycamore and silver birch) accounting for 50%. The remainder (58 tree species), store the rest of the carbon, 119,969 metric tons (or 22% of the total).

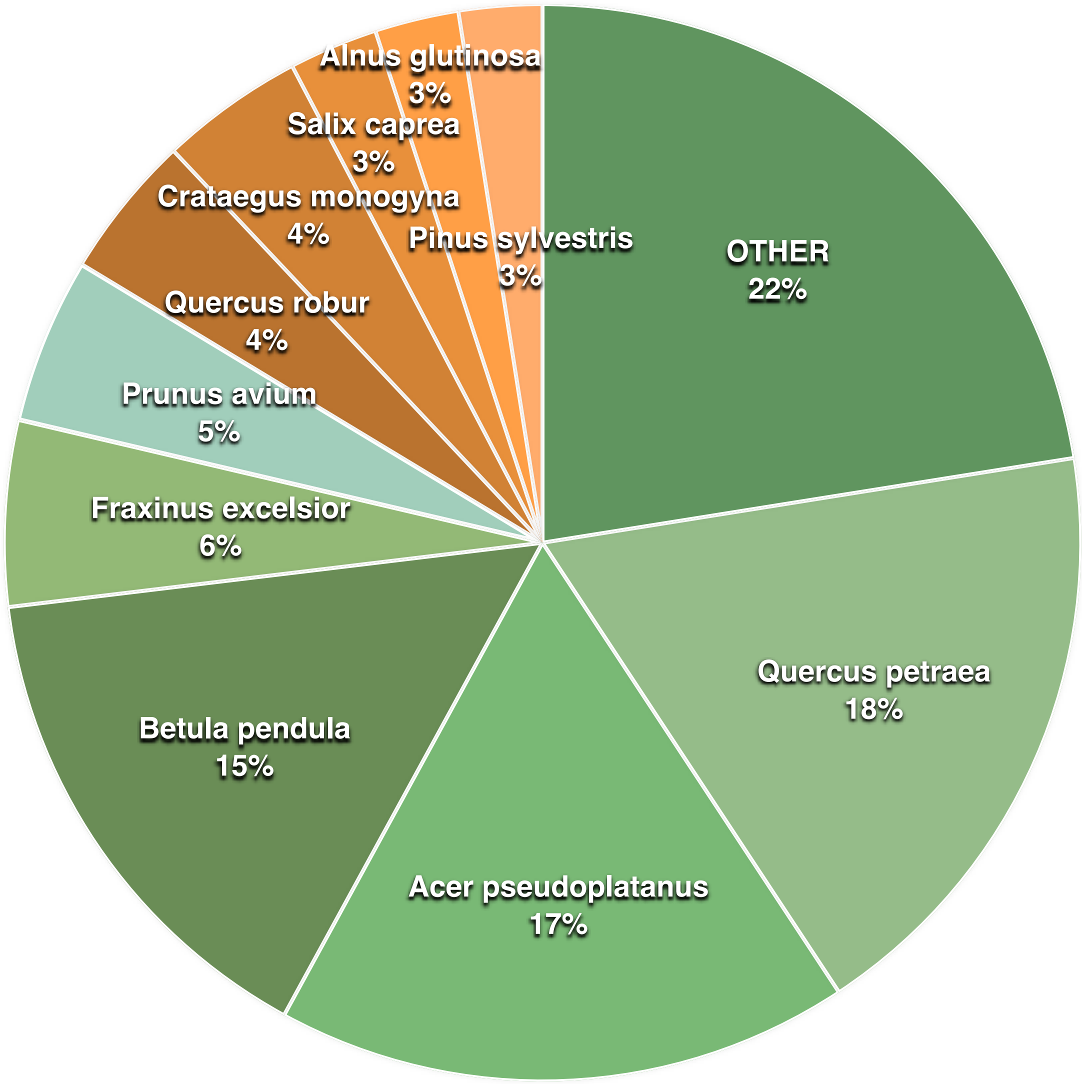


Fig 13: Carbon storage (%) by species for the top ten trees across Sheffield.

Carbon sequestration for Sheffield's trees accounts for approximately 21,837 metric tons of carbon per year (approximately 1.7t/yr/ha). For comparison, the gross amount of carbon sequestered by the urban forest across London each year is estimated at 77,200 tonnes. The value of Sheffield's sequestered carbon is estimated at £1,397,568 per year. This value will increase in a non linear fashion as the trees grow and as the social cost of carbon (its value per tonne) increases.

For Sheffield again, unsurprisingly, the picture for carbon sequestration is very similar to that of carbon storage. The top ten trees dominate the carbon sequestration, accounting for approximately 16,261 metric tons (or 74.5%) of the total (see figure 14, below). The top three trees account for over 47% of the total carbon sequestration. The remaining 58 tree species account for just 5,576 metric tons (or 25.5%).

Trees also play an important role in protecting soils, which is one of the largest terrestrial sinks of carbon. Soils are an extremely important reservoir in the carbon cycle because they contain more carbon than the atmosphere and plants combined[15].

[15] Ostle et al (2009)

Avoided Runoff and Attenuation

Surface water flooding occurs when rainfall runs off land and buildings at such a rate that it is unable to drain away in streams, rivers, drains or sewers. It is therefore distinct from river flooding or tidal flooding where rivers or the sea breach river/sea walls and defences. It is estimated that over 80, 000 homes are at high risk of surface water flooding in England and Wales[16] and that surface water flooding costs an average of £270 million per year.

According to the Sheffield Flood Risk Management Plan[17], across Sheffield 1,400 homes are at risk from surface water flooding. These are not confined to a particular location but scattered city-wide.

'Runoff' occurs in the built environment from virtually every rainfall event with streams receiving frequent discharges of polluted water from urban surfaces (hydrocarbons, suspended solids and metals etc).

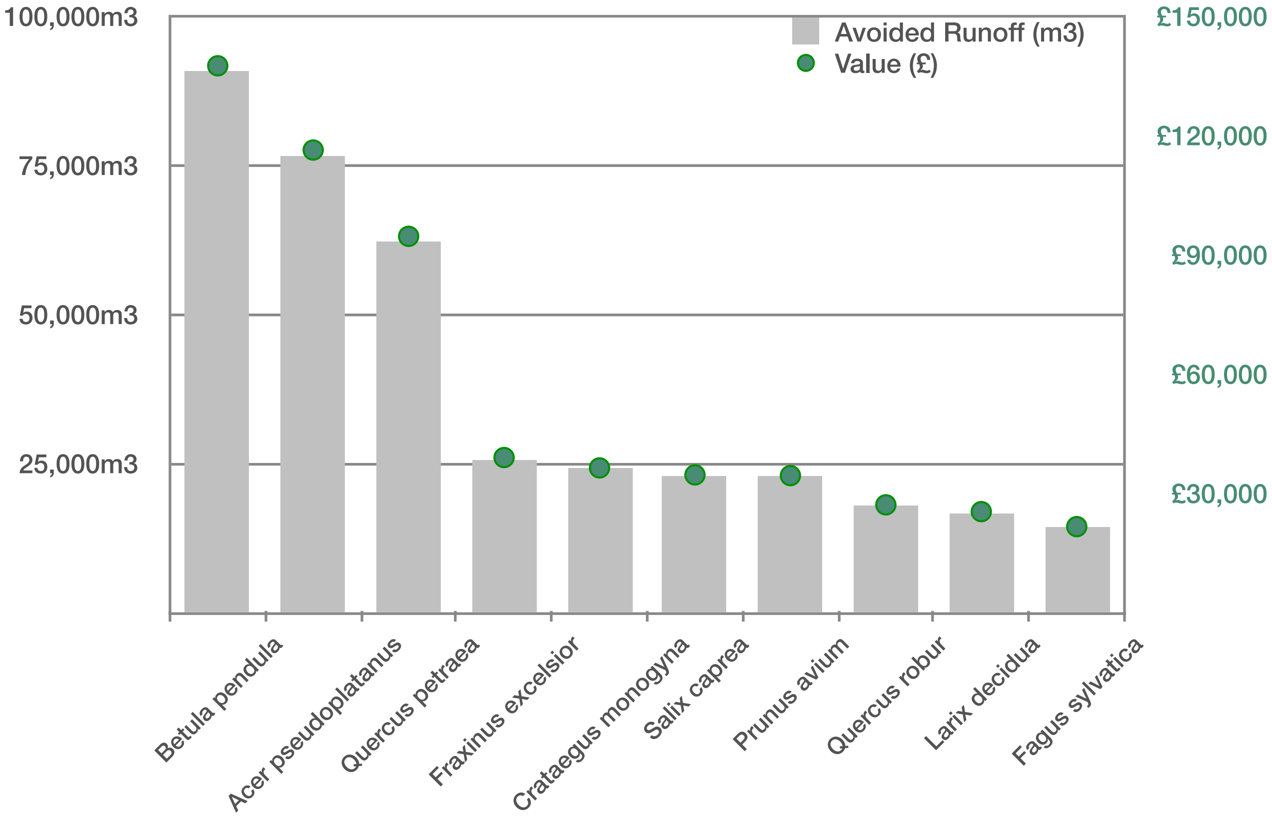


Fig 14: Quantity and value of the avoided runoff per annum for Sheffield for the top ten species

[16] London's Environment Revealed (2011)

[17] Sheffield Flood Risk Management Strategy https://www.sheffield.gov.uk/content/dam/sheffield/docs/public-health/floods/Sheffield%20Flood%20Risk%20Management%20Strategy.pdf

Trees have the potential to 'capture' an amount of water during rainfall events which is held in the canopies of the trees. After these rainfall events, this moisture is then re-evaporated into the atmosphere. The cycle may repeat many times but water cycled in this way is diverted and thereby prevented from entering combined sewers. Some of the rainfall will also be directed down the trees' network of branches and stem(s) directly into the soil at the base of the tree. In this way trees are able to attenuate or reduce runoff.

The 'value' of this benefit or ecosystem service is that if the water is diverted from the combined sewerage system then it does not have to be treated, meaning a very real saving in treatment costs and avoided energy emissions.

Sheffield has an estimated total tree population of 3,863,630 trees with a leaf area of approximately 233 km^2. The effect of this leaf area is to produce an avoided runoff of some 520,198 m3 per year. This is the equivalent of more than 202 Olympic-sized swimming pools. This avoided runoff has a value of £788,801 every year.

Fig 14 (above) illustrates the contribution of the top ten tree species across Sheffield in reducing run off and the associated value which has been calculated using the avoided sewage treatment costs and avoided energy emissions.

Ecosystem Services

Recommendations

Sheffield's trees provide a range of benefits. However, it is unlikely that access to these benefits for the residents of Sheffield are spread evenly across the city. Some areas of the city are likely to have low tree cover and poor provision of benefits.

For the benefits from trees to be maximised there has to be an identified need, the trees need to be healthy and functioning efficiently and the right species and tree location needs to be chosen to address the need. Preferably, the impact needs to be quantifiable too.

An over-arching aim of any planned change to the urban forest should be to increase resilience and diversity in accordance with objectives set out in the strategy or masterplan. The results above show a heavy reliance on a small number of species to deliver a significant proportion of the ecosystem service benefits. This leaves the urban forest of Sheffield potentially vulnerable to significant perturbations affecting a species or genus in the top ten lists given above.

Therefore it is recommended that:

6. **Following the completion of a canopy cover assessment at ward level, local air quality and social indicators such as the index of multiple deprivation should be mapped alongside tree cover to identify spaces and places where the addition of trees could help meet local need in the lowest performing wards.**

7. **Areas of most need are identified and targeted to investigate for tree planting suitability. The results should also be challenged by experts with local knowledge and experience as there may be 'barriers' to tree planting in the identified areas which will need to be addressed.**

8. **Species are selected that are appropriate to the site to maximise tree benefit delivery and realise the full site potential. It is essential that trees are planted with some level of community engagement if planting initiatives are to succeed.**

9. **The development of any tree planting programs need to be sustainable and to be co-ordinated with other local stakeholders as part of the Trees and Woodland Strategy for Sheffield.**

Tree Health, Pests and Disease Impacts

Tree Health

One of the key factors in assessing the vulnerability of the urban forest to a particular pest or disease is the overall condition of the tree population. Tree condition was measured across seven criteria (Excellent, Good, Fair, Poor, Critical, Dying or Dead) as part of this survey with guidance in the iTree Eco manual as to how trees should be classified. Figure 15 (below) shows the health of the top ten most dominant species (the combination of leaf area and population).

Figure 15 shows that there is considerable variability in the condition of the trees included in the Eco inventory. Table 7 shows the stratified results for all trees, with 79.3% of the trees assessed in the Sheffield inventory considered to be in either excellent or good condition (exhibiting less than 5% dieback). This compares well with the London iTree Eco study where 86% of the trees were found to be in an excellent or good condition.

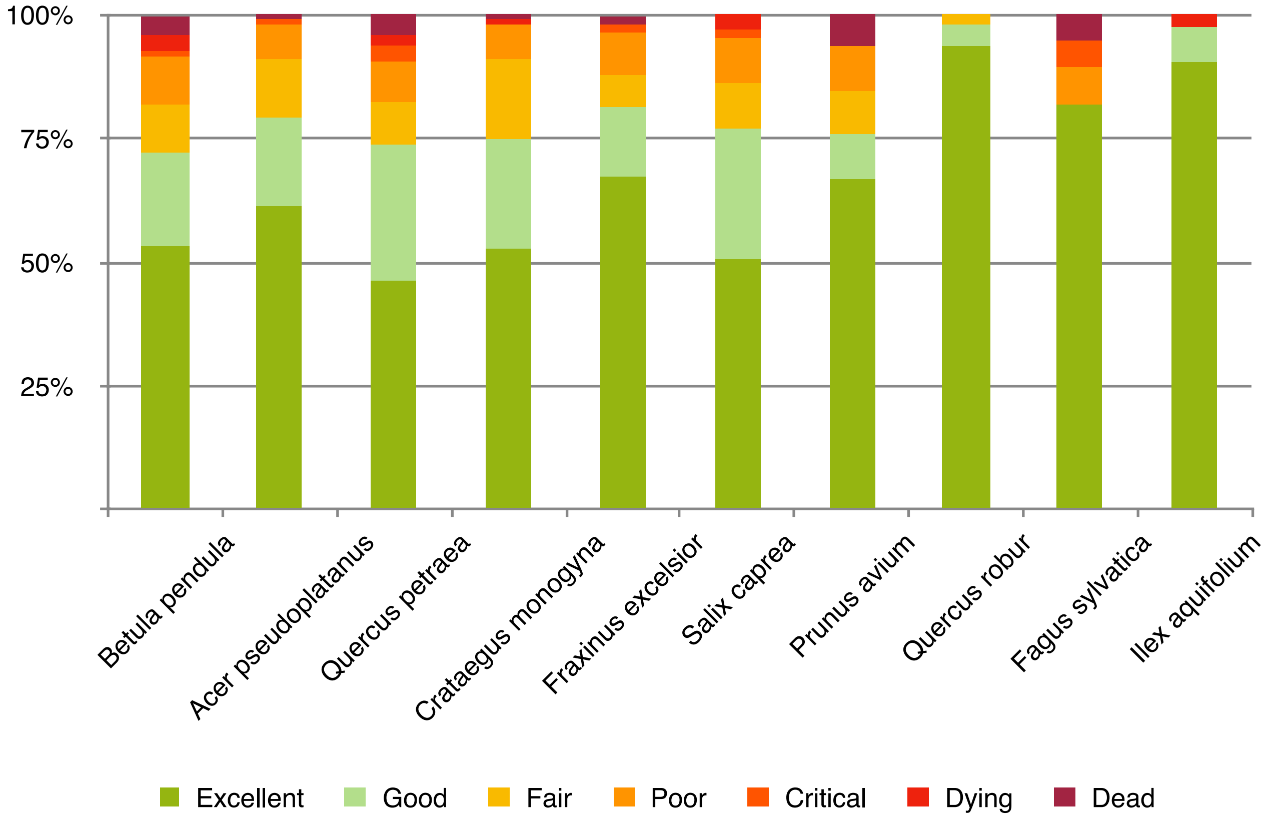


Fig 15: Tree health rating for the top ten trees (by dominance value) across the Sheffield study area

Of the three most dominant species across Sheffield, 72.1% of silver birch (*Betula pendula*), 79.1% of sycamore (*Acer pseudoplatanus*) and 73.7% of sessile oak (*Quercus petraea*) included in the inventory were considered to be in an excellent or good condition.

Stratum	Condition Rating (%)						
	Excellent	Good	Fair	Poor	Critical	Dying	Dead
Moorland	0	64.3	21.4	0	7.1	7.1	0
Urban	65.5	14.2	7.9	7.2	1.1	1.2	2.9
Total	64	15.3	8.2	7.1	1.2	1.3	2.9

Table 7: Stratified condition rating results for all tree species inventoried across the Sheffield study area

Pest and Disease Impacts

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

Severe tree pest outbreaks have occurred within living memory, such as Dutch Elm Disease, which killed approximately 30 million Elm trees in the UK throughout the late 60s and early 70s. More recently, outbreaks of *Phytophthora ramorum* (sudden oak death in the U.S) has led to the mortality of large areas of commercial larch woodland and a smaller number of amenity trees in the UK. Whilst Ash dieback (caused by the fungus *Hymenoscyphus fraxinea*) is, and will continue to cause premature mortality of native ash (*Fraxinus excelsior*). The scale of tree lost brought about by ash dieback is likely to rival that of Dutch Elm Disease.

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

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

The pest and disease analysis below only incorporates the effects from the sample plot data processed though iTree Eco.

The i-Tree Eco data can be interrogated to look at the effects of over 30 tree pests and diseases. Three of potentially the most significant identified by the council have been reviewed here.

Figure 16 (overleaf) shows what proportion of the urban forest population may be susceptible to the chosen pathogens.

Figure 17 illustrates the *theoretical* cost of replacing trees in the ‘top ten most valuable’ list (it is acknowledged that it is not actually possible to replace large mature trees) were an outbreak by one of these pathogens to take hold. The cost of replacing lost trees (Replacement Cost) is calculated within i-Tree using the Council of Tree and Landscape Appraisers (CTLA) method adapted for the UK by Hollis (2007) and endorsed by the Royal Institute of Chartered Surveyors.

Asian Long-horned Beetle (ALB) is an insect, the native range of which is in Asia. The ALB larvae bore into a wide range of hardwood species and have the potential to kill off parts of the tree (for instance large branches). This can create entry courts for other pests and diseases which may lead to the mortality of the tree. If the beetle were to become established in Britain there is likely to be extensive damage to both urban and woodland/forest trees.

This beetle could affect around 43% (or 1,661,631) of the trees in Sheffield's tree population, including sycamore (*Acer pseudoplatanus*) which makes up around 7.4% of the population and is the third most populous species, with 288,727 trees.

The fungus which is responsible for causing 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 5th most common species in Sheffield’s tree inventory, accounting for 6.6% of the population (or 253,826 trees). Ash trees can be large in stature and provide a significant amount of ecosystem services to Sheffield and so their replacement should they perish would be costly (see Figure 16).

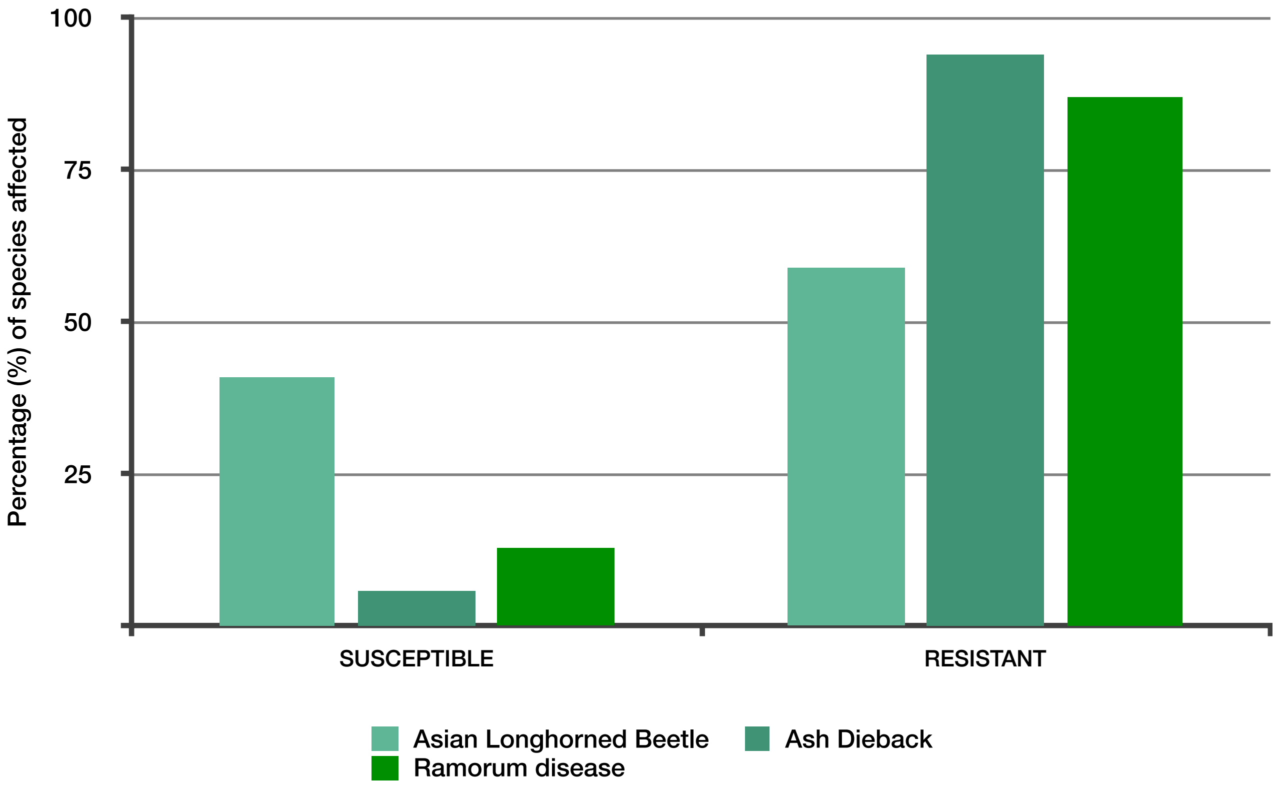


Figure 16: Chart showing the % of species susceptible and resistant to ALB, Ash dieback and *Phytophthora ramorum*

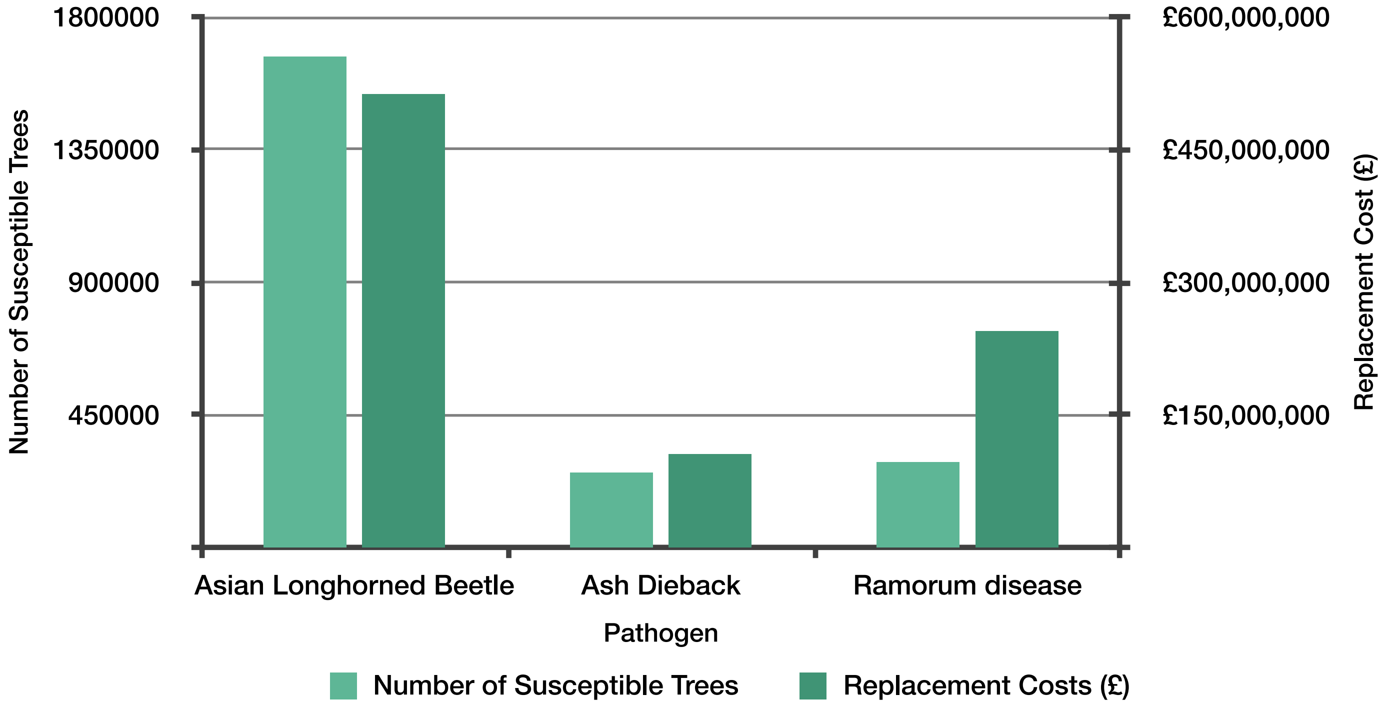


Figure 17: Chart showing the potential pest impacts on replacement cost for ALB, Ash dieback and *Phytophthora ramorum* on the top ten most valuable tree species

Phytophthora ramorum is one of a number of *Phytophthora* species which operate with varying degrees of pathogenicity on a wide range of host plant species. It has been referenced specifically here due to its highly virulent nature on a number of trees found in the UK.

Phytophthora ramorum is a water mould, known often as a 'fungus-like' pathogen. Symptoms of *Phytophthora* include stem lesions (cankers), which exude black fluid from the bark. Beneath these lesions, infected bark is dead or dying. Extensive lesions often cause tree mortality. Shoots and foliage can be affected on larch, blackened needles often found on wilted shoot tips. Infected shoots shed their needles prematurely. Larch trees also often have resinous cankers. *P ramorum* affects the leaves and shoots of a number of shrubs (including *Rhododendron*, *Camellia* and *Pieris*) causing them to wilt and blacken. Some shrubs produce huge numbers of spores.

Only tree species susceptible to the disease have been considered in producing figures 16 and 17, above. Approximately 13% of Sheffield's trees could be affected by *P ramorum* (an estimated 494,961 trees). Shrubs are also affected and often act as sources of infection (known as sporulating hosts). For example *Rhododendron ponticum* is a common amenity shrub which has become naturalised in the UK, capable of producing high numbers of spores.

Research into the effects of *P ramorum* is ongoing, and it appears that the quantity of spores which infect a host has an effect on whether a tree which has some susceptibility goes on to display symptoms or not. Larch, an important timber tree in the UK (Japanese larch (*Larix kaempferi*) in-particular is grown widely) is highly susceptible to *P ramorum*. Huge losses in commercial timber producing woodland have been seen in the UK. Varying degrees of susceptibility are seen in other tree species, including native and naturalised trees.

Recommendations

In addition to action plans to deal with outbreaks, programs for existing issues such as Ash dieback need to be enhanced in light of the new data provided by this study. Furthermore, overall tree health needs to be maintained and/or improved in order to increase resilience. Species selection for new tree planting should also be informed by the latest research into novel pests and diseases, and research into species selection for urban suitability, for example that produced by the Trees and Design Action Group (TDAG)[18].

It is therefore recommended that:

10. If not already in existence that a Pest Outbreak action plan is included as part of the overall trees and woodland strategy

11. Future tree planting programs take account of and factor in pest and disease impacts

12. To help deliver the overarching aims, tree health has to be addressed; strategies include:

i) Increasing ward level species diversity

ii) Assessing and implementing appropriate works in order to maximise tree health through an annual inspection programme

iii) Review biosecurity procedures and practices to minimise risk of outbreak

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[18] TDAG Species Selection for Green Infrastructure http://www.tdag.org.uk/species-selection-for-green-infrastructure.html

Policy Context

The Government's Forestry and Woodland Policy Statement (Defra, 2013) recognises the key role of the urban forest in engaging people with trees and woodlands on their doorstep. It notes the importance of valuing our urban trees, using tools such as i-Tree.

Urban forests can also contribute to meeting objectives 1 and 4 of Defra's strategy to 2020. These involve a cleaner, healthier environment (1) and a nation protected against floods and other hazards (4) (Defra, 2016).

In urban areas, linking trees to the National Policy Planning Framework (NPPF) is crucial and even though the policy only mentions 'trees' in the context of 'aged or veteran trees' (in paragraph 118), trees and urban tree cover are implicitly and positively linked to other key concepts that are emphasised and highlighted within the framework.

Despite the omission, the contributions that trees can make to creating vibrant, liveable and sustainable places should not be overlooked. The objectives outlined in the NPPF are all dependent on the significant contribution that trees can make. In fact, of the 13 sections in the NPPF, trees are able to contribute to meeting the objectives of 11 of them[19].

At the local level the vision of Sheffields Trees and Woodlands Strategy (2018-2033) is working in partnership to provide outstanding resilient and sustainably managed trees and woodlands which are rich, diverse, healthy, attractive and of maximum benefit to the public and wildlife. The strategy includes proposals to plant an additional 100,000 trees over the next 10 years in conjunction with a specific Tree Planting Strategy as well as to protect, enhance and promote the existing tree cover, maximising their benefits across all parts of the city whilst sustainably managing the citys extensive woodland cover to the UKWAS standard. This and other policies are summarised in table 8 below.

[19] Rogers (2017) goes through each section in further detail

Policy	Section	Relevance to Urban Forest
Sheffield Unitary Development Plan 1998 (a new 'Sheffield Plan' is currently in development)	**Green Environment (GE15) Trees and Woodland**	It is recognised that trees improve the local climate, help offset climate change and reduce pollution. Planting and protecting new woodlands are important elements in the creation of the Green Network. Trees and woodland will be encouraged and protected by planting, managing and establishing trees and woodland; requiring developers to retain mature trees, copses and hedgerows and not permitting development which would damage existing mature and ancient woodlands.
Green and Open Spaces Strategy 2010-2030	**Environment and Sustainability**	Part of the vision is to provide an even greener Sheffield – contributing on a regional scale to managing climate change and conserving biodiversity. By 2030 this Strategy will ensure that the multiple functions of Sheffield's rivers, woodland and hills and countryside are being fully utilised - countering climate change impacts, working productively for income and jobs and providing space for people's recreation and enjoyment.
Trees & Woodlands Strategy 2018-2033	**All**	The strategy contains 9 aims and 53 actions aimed at managing and enhancing the citys urban forest spanning 15 years. The iTree survey gives us valuable information on the existing resource and a baseline for setting targets on how we will maintain, protect and enhance the tree cover across the city. The information from this report will be key when carrying out future reviews of the strategy

Table 8: Summary of policy linked to Sheffield's urban forest

Turning Data into Action

Using the data from this study, the information in this report, the i-Tree program and other ongoing work, Sheffield Council have drafted 4 key aims, each of which can be addressed by the recommendations previously outlined in this report. These are presented in table 9 below.

Overall this report and its associated data can provide a baseline on the urban forest structure and its benefits. In doing so, this can support decision makers within the council to achieve social and economic and environmental objectives.

In order to meet the recommendations previously outlined in this report and address the 5 drafted aims, the recommendations should be built in to the existing Trees and Woodland Strategy as part of the next annual review.

Key Aims	Measurable	Action
Increase Tree Canopy Cover and species diversity	**% Tree canopy cover per ward** **Higher number of species recorded**	Develop city wide Tree Planting Strategy that includes: Ward level canopy cover goals and barriers Increase in species diversity Community involvement Air quality and social indicators Pests and disease impacts Right tree, right place
Increase resilience of the tree population to pests, disease and climate change	**Robust biosecurity measures**	Review Biosecurity measures around procurement, species choice and ongoing tree management. Develop Pest Outbreak Action Plan
Increase knowledge of existing resource	**Better data on the citys tree resource**	Develop inventory of trees in council ownership and produce online dashboard
Further develop T&W Strategy	**Updated information within T&W Strategy**	Carry out review of T&W Strategy and include additional information

Table 9: Key Aims for Sheffield City Counci

Replacement Cost

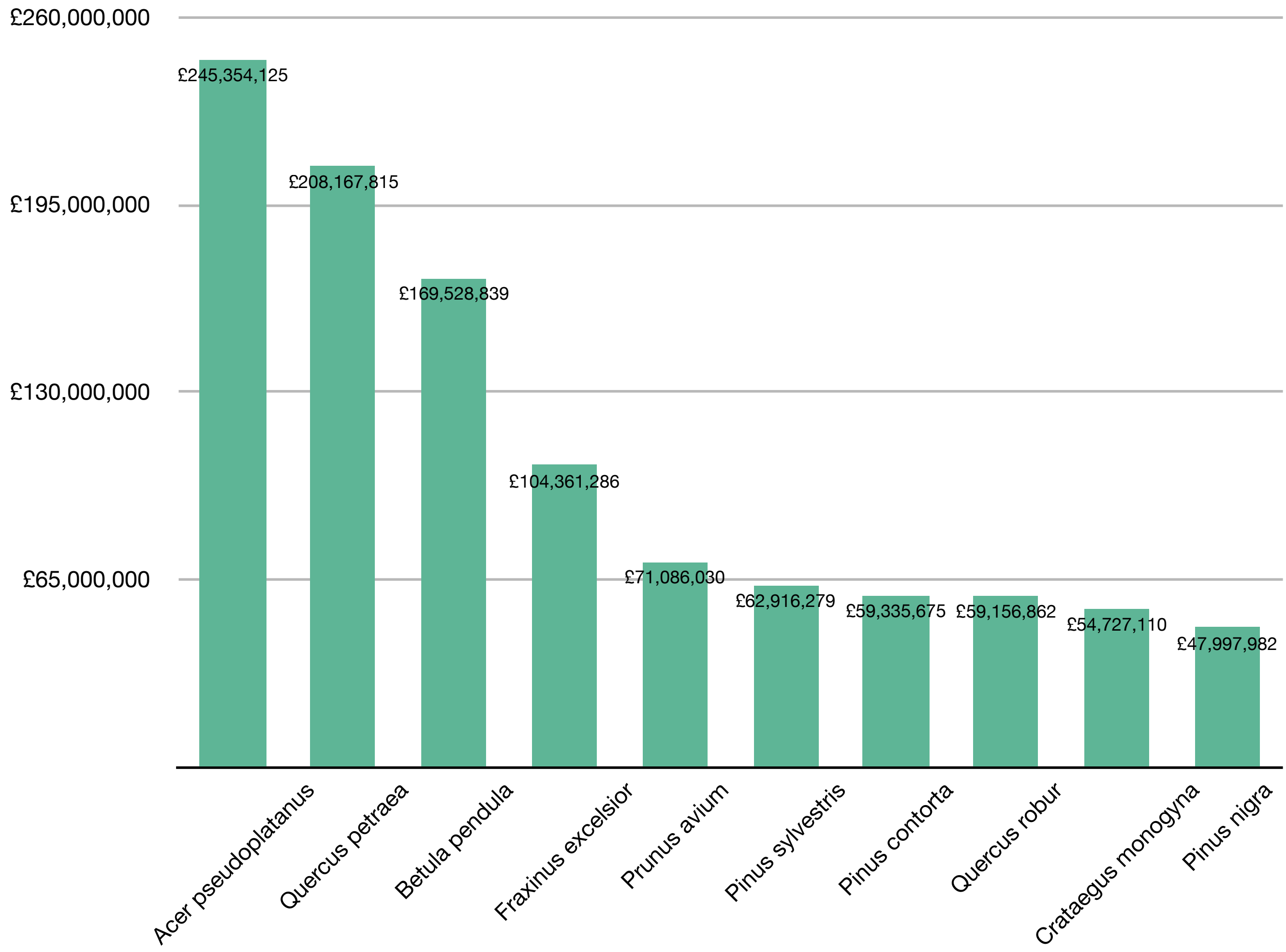

Fig 18: Replacement Cost of the ten most valuable trees across Sheffield

In addition to estimating the environmental benefits provided by trees the i-Tree Eco model also provides a structural valuation of the trees in the urban forest. In the UK this is termed the 'Replacement Cost'. It must be stressed that the way in which this value is calculated means that it does not constitute a benefit provided by the trees. The valuation is a depreciated replacement cost, based on the Council of Tree and Landscape Appraisers (CTLA) formulae[20]. The formula allows for tree suitability in the landscape and nursery prices.

Replacement Cost is intended to provide a useful management tool, as it is able to value what it might cost to replace any or all of the trees (taking account of species suitability, depreciation and other economic considerations) should they become damaged or diseased for instance. The replacement costs for the ten most valuable tree species are shown in figure 18.

The total replacement cost of all trees in Sheffield currently stands at over £1.43 billion.

[20] Hollis (2007)

Across the study area, Sycamore (*Acer pseudoplatanus*) is the most valuable species of tree, on account of both its size and population, followed by sessile oak (*Quercus petraea*) and silver birch (*Betula pendula*). These three species of tree account for over £623 million in replacement cost value, which is over 43% of the total. The top ten tree species by replacement cost account for over £1.08 billion (over 75%) of the total replacement cost.

By stratum, across the moorland area, the total replacement cost is estimated at £84,182,625. Just three species were recorded with silver birch and sessile oak of comparative value at over £40,000,000 each and hawthorn making up the remainder (over £650,000). Across the urban area, the top ten species match exactly that of the entire study area (as figure 18 shows). The total replacement cost across the urban area amounts to almost £1.35 billion (over 94% of the total study area value).

These results again show a heavy reliance on a small number of species to deliver a significant proportion of the structural value (replacement cost) of the tree population of Sheffield. This is a fairly typical picture across urban areas of the UK.

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

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. This adds another dimension to the utilitarian approach adopted in the CTLA method. 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 Sheffield's trees to include a social dimension by valuing the visual accessibility and prominence within the overall urban forest.

For the urban forest of Sheffield, the estimated total public amenity asset value is over £9.3 billion. This equates to just under £254,000 per hectare.

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 in height (to a greater or lesser extent) and are generally growing in conditions of greater stress than their open grown or woodland counterparts. As a result, they may have a significantly reduced functionality under the CAVAT system.

As stated above, Sheffield's urban forest is estimated to be worth over £9.3 billion. As an asset to Sheffield, the above figure is equivalent to over 7 times the entire budget for the City of Sheffield Region 'Devolution Deal'.

The Sycamore (*Acer pseudoplatanus*) of Sheffield holds the highest CAVAT value (Table 10, below), although the Silver birch (*Betula pendula*) is the most numerous tree, representing over 20% of the total tree population.

Scientific Name	Percent of total population	Value by Species	Value across Sheffield
Acer pseudoplatanus	7.56%	526,966	£1,857,265,582
Quercus petraea	7.56%	327,558	£1,154,460,174
Betula pendula	20.78%	273,503	£963,947,873
Crataegus monogyna	7.07%	157,960	£556,721,500
Fraxinus excelsior	6.65%	157,297	£554,386,195
Quercus robur	3.99%	135,117	£476,212,039
Pinus contorta	2.16%	113,078	£398,539,230
Prunus avium	3.74%	98,571	£347,407,520
Pinus sylvestris	3.16%	98,290	£346,418,583
Larix decidua	1.75%	78,776	£277,642,521

Table 10: Top ten most valuable trees by species as per the CAVAT methodology

The single most valuable tree encountered in the study was also a Sycamore, situated in plot 200, and estimated to have an amenity value of £50,512.

The Agricultural land-use holds most of the amenity value of trees, with the total value of trees within this land use type estimated at approximately £1.5 million for the plots sampled (including all of the woodlands in the inventory, which accounts for much of this value). This equates to 56% of the amenity value held by Sheffield's trees (Fig 19). Parks are also of great importance in Sheffield as they hold over 15% of the amenity value, a total of £695,405 for the plots sampled.

Further details on the CAVAT method are given in Appendix I.

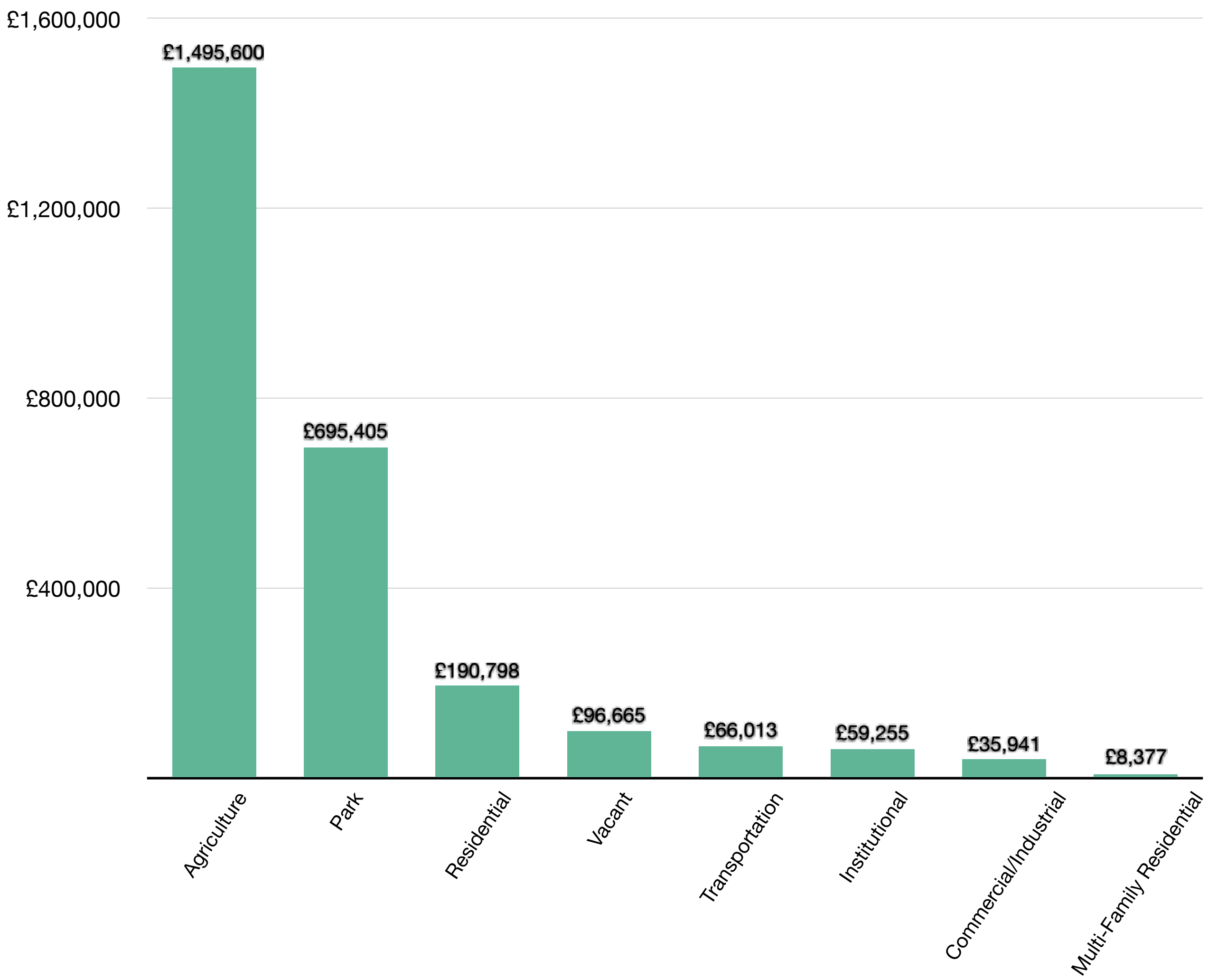

Figure 19: CAVAT value by land-use for the plots inventoried (NB: Agriculture land-use includes woodlands)

Appendix I
Notes on Methodology

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

- Forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by trees, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns and <10 microns).
- Total carbon stored and net carbon annually sequestered by trees.
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by pests, such as (but not limited to) Asian long-horned beetle, emerald ash borer, gypsy moth, and ash dieback.

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

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[21]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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.

21 Nowak, 1994

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of trees account for decomposition[22].

Recent updates (2011) to air quality modelling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulphur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models[23]. As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[24] [25] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere26.

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. The value of avoided runoff is based on estimated or user-defined local values. As the local values include the cost of treating the water as part of a combined sewage system the lower, national average externality value for the United States is utilised and converted to local currency with user-defined exchange rates.

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

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[22] Nowak, Hoehn and Crane, 2007

[23] Baldocchi, Hicks and Camara, 1987 and Baldocchi, 1988

[24] Bidwell and Fraser, 1972

[25] Lovett, 1994

[26] Zinke, 1967

[27] Hollis, 2007

[28] Rogers et al., 2012

US externality and UK social damage costs

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

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

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

Official pollution values for the UK are based on the estimated social cost of the pollutant in terms of impact upon human health, damage to buildings and crops. Values were taken from the Interdepartmental Group on Costs and Benefits (IGCB) based on work by DEFRA[30]. They are a conservative estimate because they do not include damage to ecosystems; SO_2 negatively impacts trees and freshwater and NOx contributes to acidification and eutrophication. For PM10s, which are the largest element of the air pollution benefit, a range of economic values is available depending on how urban (hence densely populated) the area under consideration is. We used the 'transport urban big' values as a conservative best fit, given the population density data above.

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

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

For UK implementation see Rogers et al. (2012).

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[29] DECC, 2011

[30] DEFRA, 2007

CAVAT

An amended CAVAT method was chosen to assess the trees in this study, in conjunction with the CAVAT steering group (as done with previous i-Tree Eco studies in the UK).

In calculating CAVAT the following data sets are required:

- the current Unit Value;
- Diameter at Breast Height (DBH);
- the CTI (Community Tree Index) rating, reflecting local population density;
- an assessment of accessibility;
- an assessment of overall functionality, (that is the health and completeness of the crown of the tree);
- an assessment of Safe Life Expectancy.

The current Unit Value is determined by the CAVAT steering group and is currently set at £15.88 (LTOA 2012).

DBH is taken directly from the field measurements. The CTI rating is determined from the approved list (LTOA 2012) and is calculated on a borough by borough basis.

Accessibility, (i.e. the extent to which the public benefit from the amenity value of trees), was generally judged to be 100% for trees in Parks, street trees and other open areas, and was generally reduced for residential areas and transportation networks to 60% (increased to 100% if the tree was on the street), to 80% on institutional land uses and to 40% on Agricultural plots. A full list is given in table 11 below.

On open spaces we divided the trees into those with 100% exposure to light, and the others, which occurred in groups. On the basis that trees in open spaces are less intensively managed we applied an 80% functionality factor to all the individual trees, a 60% factor for those in small groups and a 40% factor for those in large groups. One could simply apply an overall figure for these too, but it would not then reflect how significant a proportion of the population the trees in groups are.

Functionality was calculated directly from the amount of canopy missing.

Safe Life Expectancy assessment was intended to be as realistic as possible, but based on existing circumstances. For full details of the method refer to LTOA (2010)[31].

[31] https://www.ltoa.org.uk/documents-1/capital-asset-value-for-amenity-trees-cavat

Land Use	Street Tree?	Accessibility (%)
Agriculture	Yes	100
Agriculture	No	40
Cemetery	Yes	100
Cemetery	No	80
Commercial/Industrial	Yes	100
Commercial/Industrial	No	40
Golf Course	Yes	100
Golf Course	No	60
Institutional	Yes	100
Institutional	No	80
Multi-Family Residential	Yes	100
Multi-Family Residential	No	80
Other	Yes	100
Other	No	60
Park	Yes	100
Park	No	100
Residential	Yes	100
Residential	No	60
Transportation	Yes	100
Transportation	No	40
Utility	Yes	100
Utility	No	20
Vacant	Yes	100
Vacant	No	80
Water/Wetland	Yes	100
Water/Wetland	No	60

Table 11: Accessibility figures for CAVAT used in this report

Appendix II - Dominance Values

Rank	Species	% Population	% Leaf Area	DV
1	Betula pendula	21.20	17.40	38.60
2	Acer pseudoplatanus	7.50	14.70	22.20
3	Quercus petraea	7.80	12.00	19.80
4	Crataegus monogyna	7.10	4.60	11.80
5	Fraxinus excelsior	6.60	4.90	11.50
6	Salix caprea	5.30	4.40	9.70
7	Prunus avium	3.70	4.40	8.10
8	Quercus robur	3.90	3.40	7.40
9	Fagus sylvatica	3.10	2.70	5.90
10	Ilex aquifolium	3.40	2.20	5.60
11	Pinus sylvestris	3.10	2.30	5.40
12	Sorbus aucuparia	3.20	2.20	5.40
13	Betula pubescens	3.20	2.00	5.20
14	Larix decidua	1.70	3.20	4.90
15	Alnus glutinosa	1.70	2.70	4.40
16	Pinus contorta	2.10	1.90	4.00
17	Pinus nigra ssp. salzmannii	1.30	2.00	3.30
18	Tilia x europaea	0.70	2.50	3.20
19	Cupressocyparis leylandii	2.10	0.80	2.90
20	Corylus avellana	0.80	0.70	1.60
21	Picea sitchensis	0.10	1.10	1.20
22	Acer campestre	0.50	0.60	1.10
23	Carpinus betulus	0.20	0.90	1.10
24	Acer	0.70	0.30	1.00
25	Sambucus nigra	0.70	0.30	1.00
26	Ulmus procera	0.30	0.40	0.70
27	Crataegus crus-galli	0.50	0.20	0.70
28	Fraxinus angustifolia 'Raywood'	0.20	0.40	0.70
29	Taxus baccata	0.30	0.30	0.60
30	Sorbus aria	0.40	0.20	0.60
31	Chamaecyparis	0.40	0.20	0.60
32	Castanea sativa	0.30	0.30	0.60
33	Salix fragilis	0.20	0.30	0.60
34	Magnolia	0.30	0.20	0.60
35	Corylus	0.20	0.30	0.50
36	Syringa vulgaris	0.40	0.10	0.50
37	Cupressus	0.40	0.10	0.50
38	Malus	0.40	0.10	0.50
39	Salix	0.20	0.20	0.40
40	Ulmus glabra	0.20	0.20	0.40

Rank	Species	% Population	% Leaf Area	DV
41	Prunus padus	0.20	0.20	0.40
42	Populus balsamifera	0.10	0.30	0.40
43	Prunus cerasifera	0.20	0.10	0.30
44	Cotoneaster frigidus	0.20	0.10	0.30
45	Malus domestica	0.20	0.10	0.30
46	Fraxinus	0.20	0.10	0.30
47	Tilia cordata	0.10	0.20	0.30
48	Trachycarpus fortunei	0.20	0.10	0.20
49	Alnus incana	0.10	0.20	0.20
50	Aesculus hippocastanum	0.10	0.10	0.20
51	Prunus laurocerasus	0.20	0.10	0.20
52	Tilia platyphyllos	0.20	0.00	0.20
53	Crataegus laevigata	0.10	0.10	0.20
54	Liquidambar styraciflua	0.10	0.10	0.20
55	Betula pendula gracilis	0.10	0.10	0.10
56	Acer negundo	0.10	0.00	0.10
57	Malus sylvestris	0.10	0.00	0.10
58	Sambucus	0.10	0.00	0.10
59	Eucalyptus dalrympleana	0.10	0.00	0.10
60	Laurus nobilis	0.10	0.00	0.10
61	Cotoneaster	0.10	0.00	0.10
62	Laurus	0.10	0.00	0.10
63	Cupressocyparis	0.10	0.00	0.10
64	Pinus nigra	0.10	0.00	0.10
65	Forsythia	0.10	0.00	0.10
66	Syringa	0.10	0.00	0.10
67	Fraxinus anomala	0.10	0.00	0.10
68	Ulmus	0.10	0.00	0.10

Appendix III - Tree Species List

Species	No. of trees	Leaf Area (m2)	Carbon Storage (mt/yr)	Gross C Seq (mt/yr)	Avoided Runoff (m3/yr)	Pollution Removal (mt/yr)	Replacement Cost (£)
Betula pendula	818,089	40,657,290	82,481	4,482	90,681	25	£169,528,839
Quercus petraea	301,168	10,231,250	99,460	3,101	62,394	17	£208,167,815
Acer pseudoplatanus	288,727	8,003,410	94,036	2,744	76,707	21	£245,354,125
Crataegus monogyna	275,911	10,177,200	23,580	1,219	23,981	7	£54,727,110
Fraxinus excelsior	253,826	5,211,250	30,407	1,035	25,701	7	£104,361,286
Salix caprea	206,234	1,803,630	14,574	686	22,820	6	£37,316,931
Quercus robur	152,296	4,447,990	23,599	856	17,851	5	£59,156,862
Prunus avium	142,777	6,272,300	27,192	1,051	22,699	6	£71,086,030
Ilex aquifolium	130,086	757,830	9,813	488	11,623	3	£23,418,294
Betula pubescens	123,740	733,480	8,000	494	10,489	3	£15,675,857
Sorbus aucuparia	123,740	1,333,530	9,230	574	11,297	3	£25,252,116
Fagus sylvatica	120,568	555,960	10,870	488	14,237	4	£17,975,706
Pinus sylvestris	120,568	285,800	13,636	513	12,070	3	£62,916,279
Cupressocyparis leylandii	82,494	594,620	1,977	170	4,023	1	£8,080,959
Pinus contorta	82,494	525,430	11,946	363	9,921	3	£59,335,675
Alnus glutinosa	66,629	738,320	13,753	507	13,990	4	£39,760,447
Larix decidua	66,629	372,000	11,209	312	16,728	5	£20,359,412
Pinus nigra ssp. salzmannii	50,765	456,180	10,506	322	10,270	3	£47,997,982
Corylus avellana	31,728	785,290	1,775	127	3,858	1	£4,275,914
Tilia x europaea	28,555	317,250	4,757	252	13,015	4	£25,039,664
Acer	25,383	116,850	1,659	83	1,690	0	£4,350,713
Sambucus nigra	25,383	108,830	1,626	111	1,636	0	£5,262,075
Acer campestre	19,037	180,510	1,493	80	2,974	1	£5,763,856
Crataegus crus-galli	19,037	39,750	1,035	100	1,240	0	£2,796,729
Chamaecyparis	15,864	253,430	734	51	1,002	0	£4,440,768
Cupressus	15,864	26,910	495	46	460	0	£2,291,606

Species	No. of trees	Leaf Area (m2)	Carbon Storage (mt/yr)	Gross C Seq (mt/yr)	Avoided Runoff (m3/yr)	Pollution Removal (mt/yr)	Replacement Cost (£)
Malus	15,864	60,350	209	52	424	0	£1,189,811
Sorbus aria	15,864	27,974,770	1,276	62	1,067	0	£4,204,428
Syringa vulgaris	15,864	34,392,140	269	37	637	0	£1,156,318
Castanea sativa	12,691	10,751,820	2,163	83	1,326	0	£5,771,196
Magnolia	12,691	11,523,180	285	37	1,172	0	£1,120,241
Taxus baccata	12,691	4,702,800	391	19	1,647	0	£2,451,996
Ulmus procera	12,691	5,065,080	941	37	2,110	1	£931,252
Corylus	9,518	6,383,300	1,950	83	1,552	0	£5,660,562
Fraxinus angustifolia 'Raywood'	9,518	5,411,800	363	49	2,114	1	£1,779,429
Prunus cerasifera	9,518	7,500,220	525	52	348	0	£817,983
Prunus padus	9,518	4,604,640	819	45	830	0	£2,648,835
Salix	9,518	1,729,940	176	29	1,017	0	£672,640
Salix fragilis	9,518	5,835,360	4,760	93	1,752	0	£3,364,134
Ulmus glabra	9,518	449,230	382	23	911	0	£663,055
Carpinus betulus	6,346	206,170	3,986	117	4,676	1	£10,274,022
Cotoneaster frigidus	6,346	190,280	571	64	745	0	£1,554,111
Fraxinus	6,346	478,480	5,516	208	586	0	£26,871,884
Malus domestica	6,346	946,030	320	48	708	0	£864,474
Prunus laurocerasus	6,346	695,690	70	18	261	0	£475,924
Tilia platyphyllos	6,346	947,820	83	11	243	0	£409,295
Trachycarpus fortunei	6,346	156,100	20	0	403	0	£3,307,362
Acer negundo	3,173	408,240	23	8	248	0	£237,962
Aesculus hippocastanum	3,173	2,096,490	148	13	780	0	£263,824
Alnus incana	3,173	334,170	1,543	83	782	0	£3,931,808
Betula pendula gracilis	3,173	262,580	125	23	338	0	£311,211
Cotoneaster	3,173	111,400	78	16	89	0	£161,581
Crataegus laevigata	3,173	349,520	368	20	565	0	£1,148,849

Species	No. of trees	Leaf Area (m2)	Carbon Storage (mt/yr)	Gross C Seq (mt/yr)	Avoided Runoff (m3/yr)	Pollution Removal (mt/yr)	Replacement Cost (£)
Cupressocyparis	3,173	350,490	35	7	60	0	£157,055
Eucalyptus dalrympleana	3,173	151,370	20	7	135	0	£157,055
Forsythia	3,173	20,530	30	9	46	0	£203,593
Fraxinus anomala	3,173	10,650	20	3	24	0	£158,641
Laurus	3,173	37,470	162	23	84	0	£434,699
Laurus nobilis	3,173	40,680	73	8	91	0	£237,962
Liquidambar styraciflua	3,173	196,130	49	8	437	0	£178,925
Malus sylvestris	3,173	84,840	40	8	189	0	£114,222
Pinus nigra	3,173	22,690	31	6	51	0	£237,962
Picea sitchensis	3,173	407,250	5,599	81	5,671	2	£18,541,833
Populus balsamifera	3,173	0	1,258	43	1,614	0	£1,924,346
Sambucus	3,173	2,542,660	255	16	170	0	£709,032
Syringa	3,173	723,600	17	3	33	0	£195,129
Tilia cordata	3,173	76,240	387	33	908	0	£1,946,255
Ulmus	3,173	14,880	139	0	0	0	£0

Appendix IV - Relative Tree Effects

The trees in Sheffield 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).

Leaf area is equivalent to:
- 31,888 Hillsborough football pitches

- More than 63% of the total surface area of Sheffield

Carbon storage is equivalent to:
- Amount of carbon emitted across Sheffield in 75 days

Annual carbon sequestration is equivalent to:
- Annual carbon emissions from 17,000 cars

Annual nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 17,700 cars

Storm water alleviation is equivalent to:
- 202 Olympic-sized swimming pools

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).

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