The value of Peterborough City Council's trees

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Executive summary

Urban trees provide numerous environmental, ecological and social benefits. Until recently, these benefits were rarely recognised or valued, whereas the costs of damage and management are widely reported, meaning that trees can be viewed as a liability rather than an asset. Understanding of the importance of urban trees for delivering multiple benefits is, however, being increasingly understood and tools now exist for quantifying these benefits and their associated monetary value. Valuing urban trees is helping to change perceptions of public trees and allows for better and more informed management decisions to be made.

This report presents an evaluation of some of the benefits provided by Peterborough's council owned tree stock and was commissioned by Peterborough City Council. i-Tree Eco v6 was used to describe the tree stock and quantify and value air pollution removal, carbon storage, carbon sequestration and reductions in surface water runoff delivered by the trees. Amenity value of the tree stock was calculated using the Capital Asset Value for Amenity Trees (CAVAT) quick method. The results were based on a council inventory of single trees surveyed in the field, and informed estimates of tree groups (areas of shelterbelt and ancient woodlands). The key findings are presented in the table below for the whole of Peterborough and were also calculated for each ward.

Peterborough's council owned trees are providing significant benefits to society in the form of public services. Amenity value far outweighs the other benefits, with a total value of £2.9 billion, compared to a present value of £38.20 million over 80 years for all other benefits combined, plus total carbon storage value of £11.07 million.

Key findings

	Single trees	Tree groups	Total	Present value[a]
Number/area of trees	37,950	350ha		
Most common species	Sycamore, Norway maple, European ash	European ash, elm, hazel		
Total Annual benefits	£196,215	£1,067,711	£1,263,926	£38,199,003
Pollution removal (annual)	£91,566	£513,536	£605,102	£18,287,709
Carbon storage	£3,004,699	£8,068,010	£11,072,709	n/a
Carbon sequestration (annual)	£78,594	£419,677	£498,271	£15,059,008
Avoided surface water runoff (annual)	£26,054	£134,498	£160,552	£4,852,286
Amenity value (CAVAT)	£564M	£2,293.14M	£2,856.70M	n/a

[a]Present value is calculated over 80 years

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1. Background

Urban trees provide a wide range of benefits to society, ranging from carbon storage to improving air quality, as well as providing visual attractiveness, character and local distinctiveness. These benefits are rarely recognised or valued, whereas the costs of damage and management are widely reported, meaning that trees can be viewed as a liability rather than an asset. The importance of urban trees for delivering multiple benefits is, however, being increasingly documented and methods established for quantifying these services. Understanding the range and value of benefits provided by urban trees and how these vary with location is a key step in achieving more sustainable management of these assets.

1.1 Aims

Natural Capital Solutions were commissioned by Peterborough City Council to undertake a monetary valuation of the benefits provided by the council tree stock. The assessment summarises the council-owned tree stock, the flow of a selection of benefits delivered by the trees, and their value to society. Note that the council-owned tree stock is a subset of the total tree stock across Peterborough.

1.2 The natural capital approach

The natural environment underpins our well-being and economic prosperity, providing multiple benefits to society, yet is consistently undervalued in decision-making. Natural capital is defined as “*..elements of nature that directly or indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions”* (Natural Capital Committee 2014). These benefits (often referred to as ecosystem services) include food production, regulation of flooding and climate, pollination of crops, and cultural benefits such as aesthetic value and recreational opportunities (Figure 1).

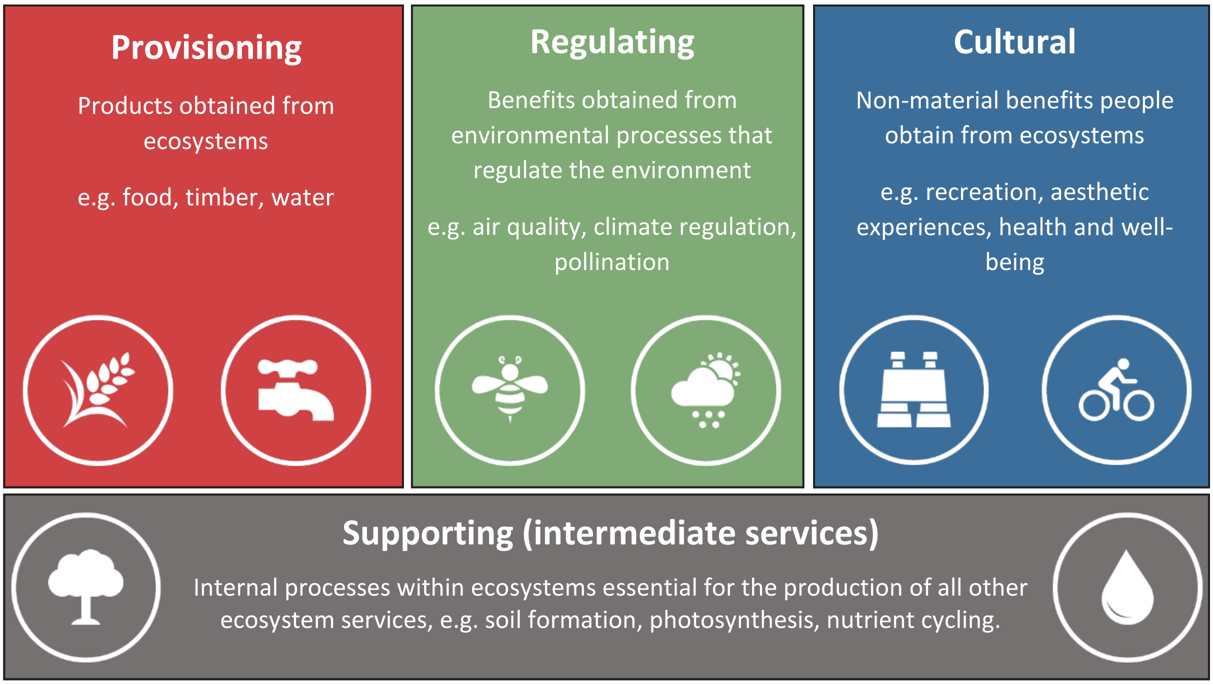

Figure 1. Key types of ecosystem services (based on MA 2005)

The concept of natural capital and its associated approaches can be used to understand the natural capital assets of an area or organisation. Through a natural capital assessment, it is possible to understand the extent and condition of those assets, so the number and the flow of ecosystem service benefits from those assets can be established. These benefits can then be valued. Information on condition, benefits and their value allows informed and transparent management decisions to be made. Furthermore, adopting the natural capital and ecosystem services approach is a key policy objective of the UK Government and is central to Defra's new 25-year Environment plan.

The approach taken in this report is based on the natural capital approach, with Peterborough's trees being the natural capital assets described, and the benefits and services derived from them quantified and valued. By taking this approach, Peterborough Council will be able to more accurately demonstrate the value of their tree stock, allowing natural capital to be taken in to account more fully in decision making. The analysis presented here also acts as a baseline, allowing the council to monitor losses and gains over time.

1.3 The benefits provided by trees and their valuation

The vast range of services provided by urban trees is summarised in Table 1. Very few of these services can be valued using existing markets, with the exception of the provisioning services such as timber, woodfuel and other bioenergy uses. A range of methods have therefore been developed to value some of the other benefits provided by trees, for which there is not currently a market, many of which have been packaged into tools for use by practitioners. One of the most complete tools available to measure multiple urban tree benefits is a software package, i-Tree Eco, which has been developed over many years by the United States Department of Agriculture Forest Service. i-Tree Eco has been successfully applied in more than 100 countries and several UK cities and provides valuations of benefits such as air pollution absorption, carbon storage and sequestration and surface water runoff reduction, all of which are described in more detail below.

Table 1: The ecosystem service benefits provided by urban trees and some of the ecological and economic implications of these services.

Ecosystem services	
Regulating services	
Reducing rate and volume of storm water runoff	Providing shade
Reducing flood risk	Reducing summer air temperatures and the urban heat island effect
Enhancing infiltration and recharging ground water	Providing shelter from wind
Reducing soil erosion	Reducing energy use
Trapping sediment	Reducing glare
Enhancing water quality	Attenuating noise
Absorbing air pollution – particulate matter (PM), NO_x, SO_3, ozone, carbon monoxide, ammonia	Screening unattractive or noisy places
Removing dust and odour	Supporting pollinators
Producing oxygen	Enhancing pest and disease control
Sequestering and storing carbon – directly and in soil	
Cultural services	
Providing and enhancing landscape character	Enhancing community cohesion
Contributing to sense of place and identity	Reducing aggression, violence and crime rates
Part of cultural heritage	Increasing security
Enhancing aesthetics	Enhancing driver and pedestrian safety
Benefiting physical health – reducing blood pressure, stress, asthma	Reducing road traffic speeds
	Enhancing privacy
Speeding recovery from surgery and illness	Bringing people closer to nature
Enhancing attention and cognitive function	Providing setting for outdoor learning
Improving mental health and well-being	Improving educational outcomes through improvements in concentration and performance and reduced time off for illness
Improving pregnancy and birth outcomes	
Reducing mortality rates – especially related to cardiovascular and respiratory diseases	Enhancing quality of life
Encouraging physical activity	Providing spiritual value and meaning
Enhancing connectivity	Supporting biodiversity and wildlife viewing
Provisioning services	
Source of timber, fuel, fodder, fruits, nuts and berries	Source of biofuels
Enhancing water supply	
Ecological benefits	
Habitat provision, improvement & connectivity	
Economic benefits	
Increasing land and property prices	Reducing heating and cooling costs
Reducing 'time on market' for selling property	Increasing property taxes
Attracting business and customers	Enhancing rental income
Reducing health care costs	Increasing tourism and visitor revenues
Reducing expenditure on air pollution removal	Reducing screening costs especially next to main roads
Reducing expenditure on storm water infrastructure	Providing potential for carbon offsetting trade
Reducing expenditure on flood defences	Generating income from sales of food, fibre, biofuels
Saving investment in new power supplies	Creating jobs and employment in environmental sector

Air quality amelioration

According to the World Health Organisation, air pollution is the greatest environmental health risk in Western Europe and globally. Exposure to air pollution in the UK causes around 40,000 deaths each year and plays a major role in cancer, asthma, stroke, heart disease, diabetes, obesity, and changes linked to dementia (RCP 2016). The cost has been estimated at more than £20 billion per year (RCP 2016) and the government is under increasing pressure to tackle the problem more effectively (e.g. House of Commons 2018). Although policies to implement clean air zones and encourage the uptake of electric vehicles, will have much the greatest impact on air pollution, the natural environment can also play a role.

Urban trees can be effective at mitigating the effects of air pollution primarily by intercepting airborne particulate matter (PM), but also by absorbing ozone, sulphur dioxide (SO_2) and nitrogen oxides (NO_X) (Elmqvist et al. 2015). The effectiveness of trees in reducing air pollution varies greatly depending on multiple factors including species, environmental conditions and concentration of pollutants (Sæbø et al. 2012, Broadmeadow and Freer-Smith 1996).

Although the average percent air quality improvement due to vegetation is relatively low, the improvement is for multiple pollutants and the actual magnitude of pollution removal can be significant, the associated monetary value of which can be very high (Rouquette and Holt 2017).

Trees can also contribute to air pollution as they emit volatile organic compounds that can lead to the formation of pollutants such as ozone and carbon monoxide. Whether trees are a net source or sink of pollution varies depending on multiple factors including species and street characteristics, though studies have concluded that an increase in tree cover usually leads to reduced ozone formation (Nowak Dwyer 2000).

Carbon storage and sequestration

Carbon storage and sequestration is seen as increasingly important as we move towards a low-carbon future. The importance of managing land and vegetation as a carbon store has been recognised by the UK government and has a major role to play in national carbon accounting. Carbon is increasingly being given a monetary value and forms the basis of Payments for Ecosystem Services (PES) schemes such as the UK Woodland Carbon Code. Trees, especially large ones, are able to store and sequester significant amounts of carbon and also facilitate a gradual accumulation of carbon in the soil (Forest Research 2010).

Avoided surface water runoff

The intensity of rainfall and storm events has increased in recent years throughout the UK, increasing the number of flood events and causing billions of pounds worth of damage. Urban drainage systems are thus increasingly under pressure, but these are costly and often outdated. There are a number of mechanisms by which trees can help alleviate the amount of urban surface water and hence reduce flood risk (Nisbet et al. 2011, Mullaney et al. 2015) including direct interception of rainwater, promoting higher infiltration rates into the soil and through greater water use. Trees can therefore significantly reduce pressure on drainage systems in urban areas, although the extent varies depending on factors such as tree size, species and intensity and duration of rainfall.

Amenity value

Urban trees also deliver cultural, non-material benefits such as aesthetic inspiration and cultural identity that are not captured in i-Tree Eco. There is, however, another tool often used in conjunction with i-Tree Eco (which values a subset of benefits) that can better capture these more social aspects of urban tree benefits, providing an indication of the amenity value of individual trees. The Capital Asset Value for Amenity Trees (CAVAT) method is an expert-based amenity tree valuation tool developed by the London Tree Officers Association (Neilan 2010). CAVAT was designed as an asset management tool for trees that are publicly owned, or of public importance, helping to change perceptions of public trees into that of assets and not liabilities (as well as a means of gaining appropriate compensation where public trees are damaged or removed).

We use a combination of both i-Tree Eco and CAVAT valuation to describe the structure of Peterborough's tree population and quantify some of the benefits delivered by this tree stock.

2. Methodology

2.1 Tree data and benefit analysis

A detailed inventory of Peterborough's public tree stock was provided by the council from surveys undertaken between July 2012 and April 2018. This dataset was used to conduct a Full Inventory assessment in i-Tree Eco v6. This provides a summary of the basic structure of the tree population and quantifies the amount and value of pollution removal, carbon storage, carbon sequestration and avoided surface water runoff services delivered by the tree stock (see Annex 1 for full details of model calculations).

The minimum data required to run i-Tree Eco is tree species and trunk diameter at breast height (DBH), however the more information included for each tree, the more accurate the results. We therefore also included tree height in the i-Tree models, but no other tree data could be incorporated. All trees within the inventory that were missing information regarding tree species, DBH and height were removed prior to analysis (3,976 entries). Dead trees and those listed as felled were also removed.

The dataset was also used to calculate the amenity value of trees using the Quick CAVAT Method (See Annex 2 for full details, Nielan 2017). In order to calculate the CAVAT value, the life expectancy and functional value of the tree (how well a tree is performing biologically) is required in addition to DBH. All entries within the inventory missing this information were removed (552 entries). The amenity value of a tree is also dependent on the human population density of the nearby area, as trees that are seen by more people will have higher value. Each tree was therefore assigned to the ward in which it was situated, and the Community Tree Index (CTI) Factor within the CAVAT calculation was adjusted according to the population density of each ward. Ward population densities were taken from the 2011 census.

The final dataset consisted of 37,950 single trees across Peterborough. In addition to these single trees, there are also a number of tree groups and woodlands within Peterborough. These broadly fall into one of two categories; shelterbelts planted along Peterborough's main roads, and ancient woodland. Exact data on individual trees within these trees groups was not available. Estimates of characteristics required to run i-Tree Eco and the CAVAT method in order to value these tree groups were therefore derived using a combination of information provided by the council and average values from the database of single trees. These estimates thus need to be considered with caution, but are able to give us a broad understanding of the contribution tree groups make to benefit delivery in Peterborough and their associated value.

The majority (63%) of the shelterbelt trees in Peterborough were planted in a four year period in the late 1970s and 93% are 30-50 years old. The species mix and density of different tree sizes (by DBH) are known from council surveys and were used as the basis for determining the average composition of a typical hectare of shelterbelt tree group (see Annex 3).

The same process was taken for the two areas of ancient woodland within Peterborough, with tree characteristics and species composition again estimated from sample surveys provided by Peterborough Council. These woods typically contain large mature standards, interspersed with a much larger number of smaller trees, typically about 30 years old, that have developed from coppice stools. Estimates of DBH were provided for the ancient woodland standards. For the younger trees developed from coppice stools, the range of DBHs of the shelterbelt trees was applied, as these were of a similar age (see Annex 3 for the full details of the ancient tree group composition estimate and how this was derived).

i-Tree and CAVAT values were derived for these typical hectares of shelterbelt and ancient woodland and then multiplied by the area of both tree group types within each ward to give an estimated value of the tree stock per ward. To calculate the area of tree groups per ward, entries representing discrete tree groups within the main Peterborough tree inventory were identified, extracted and displayed in GIS (a total of 1362 polygons). There were a number of council owned tree groups missing from this layer. Therefore, a separate "shelterbelts" layer supplied by Peterborough Council was examined, and an additional 101 polygons that did not appear on the first layer were selected and combined with the first layer. A layer showing ancient woodland sites across the study area was consulted to identify which polygons should be classified as ancient woodland. Following discussion with Peterborough Council, all other polygons were classified as shelterbelt. Finally, each of the final polygons was assigned to the ward in which it was centred and the area of shelterbelt and ancient woodland within each ward was calculated. These ward estimates were then summed to give the total estimated value of the Peterborough tree groups stock. Caution must be taken in interpreting the CAVAT value for tree groups as the CAVAT method was designed for individual trees and does not enable any account to be made of the number of trees in a group.

All analyses were therefore grouped in to two. One set of analyses were conducted on the single trees contained in the council inventory, totalling 37,950 trees. This dataset is henceforth referred to as "single trees" and is based on data collected in the field. The second set of analyses were conducted on the tree groups and woodlands, henceforth referred to as "tree groups", where some tree characteristics were based on informed estimates, totalling an estimated 349 ha of trees. All analyses were conducted both for Peterborough as a whole and by ward (removal of pollutants could not be incorporated into ward estimates as i-Tree does not break down pollution removal figures by ward). The mean value per tree, for air pollution removal, carbon storage and sequestration, and avoided runoff was also calculated for the single trees only, given the higher accuracy of this dataset.

The Present Value (PV) was determined for each of the benefits (excluding carbon storage and CAVAT values), which is a standard approach based on the Government's Green Book (HM Treasury 2018). This approach calculates the value of the flow of benefits over a given time period and is based on the concept that people generally prefer to receive goods and services now rather than later. A benefit delivered 80 years in the future is thus likely to be of less value than that same benefit delivered today. Discount rates are applied to the annual value of benefits at particular time junctures into the future to calculate the value of that benefit over a given number of years in present value terms. We applied discount rates from the HM Treasury (2018), and the ONS (2014) to calculate the value of flows of benefits of Peterborough's trees over an 80 year period. A period of 80 years was chosen as CAVAT values are calculated over this same time period as it is considered to represent average human life expectancy in the UK. This allows for total CAVAT values and PVs of the other tree benefits to be compared. Note that there will be considerable turnover over the 80 years, with many trees dying and being replaced, with surviving trees likely to increase in value over that time. The asset value therefore represents the average value of the tree stock over an 80 year period, assuming the overall number of trees remains constant.

Carbon in vegetation and soil is a stock (i.e. a quantity of resource measurable at a fixed point of time) and not a benefit that is accrued over a period of time, hence PV cannot be calculated for carbon storage benefits.

3. Results

3.1 The Peterborough tree stock

Single trees

Complete measurements were available from approximately 38,000 single trees across Peterborough. The most common species of single trees are Sycamore (*Acer pseudoplatanus*, 9.5%), Norway maple (*Acer platanoides*, 9%) and European ash (*Fraxinus excelsior*, 8%). The full breakdown of species composition is given in Figure 2. The wards with the greatest density of single public trees are Bretton (15.9/ha), followed by Dogsthorpe (9.7/ha) and Ravensthorpe (8.8/ha).

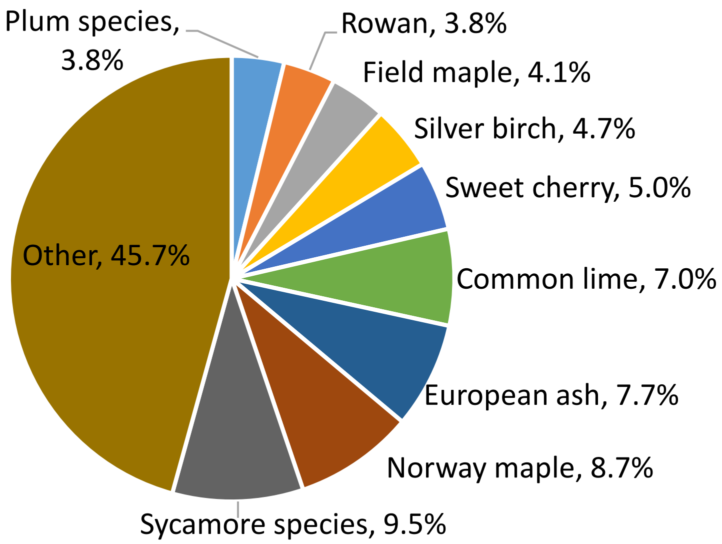

Figure 2: Species composition of council owned single trees in Peterborough.

It is estimated that 52% of the single public trees in Peterborough have a DBH of less than 30cm, while 40% have a DBH of 30-60cm and the remaining 8% have a DBH of greater than 60cm.

Tree groups

Tree groups cover approximately 350 hectares of Peterborough (330ha of shelterbelt and 20ha of ancient woodland). The most common species of trees within the shelterbelt groups are ash (Fraxinus species, 18.5%), field maple (Acer campestre, 14.3%) and hawthorn (Crataegus species, 11.5%). A full species composition breakdown is given in Figure 3. The wards with the greatest area of shelterbelt are Hargate and Hempsted (51.2ha), Orton Waterville (40.6ha) and Orton Longueville (30.9ha).

Previous surveys conducted by the council estimated that the proportion of trees in a typical hectare of shelterbelt with a DBH of 0-20cm was 67.4%, while trees with a DBH of 21-40cm make up 31.9% of shelterbelts, with a final 0.8% of shelterbelt trees having a DBH of 41-60cm. Shelterbelt trees are therefore typically smaller on average than the single measured trees described above.

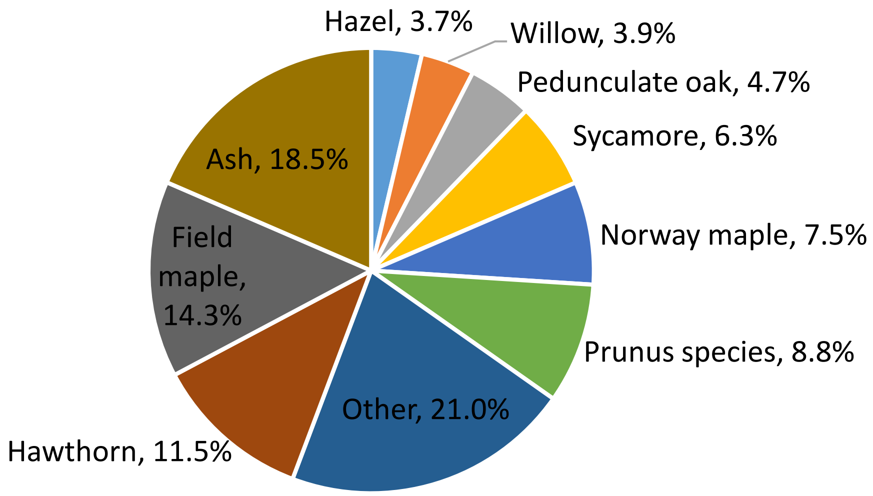

Figure 3: Estimated species composition of council owned shelterbelt trees in Peterborough.

There are two areas of ancient woodland in Peterborough, Grimeshaw Wood and Pockocks Wood. The larger of the two (Grimeshaw Wood) is in the ward of Bretton and is approximately 18ha in size. The smaller area of ancient woodland is in the ward of Glinton and Castor and covers roughly 2ha. These woods both contain approximately 286 medium and large mature standards per hectare, interspersed with a much larger number of smaller tress (roughly 1340), typically about 30 years old that have developed from coppice stools. The standards are dominated by ash (roughly 57%) and oak trees (roughly 16%) with a full breakdown given in Figure 4a. The most common species of trees within the understorey of these woodlands are elm (Ulmus species, 34%), hazel (Corylus species, 31%) and ash (Fraxinus species, 10%). A full species composition breakdown is given in Figure 4b.

The medium and large ash and oak trees typically have DBHs of 21-60cm and 61-120cm respectively and make up approximately 13.7% of the ancient woodlands. The remaining standards in a typical hectare are a variety of species and different sizes and make up 5.0% of the ancient woodlands. No information was available for the DBHs of the coppice trees but as these were a similar age to the shelterbelt trees, they were allocated the same proportion split of DBHs as these stands (see above).

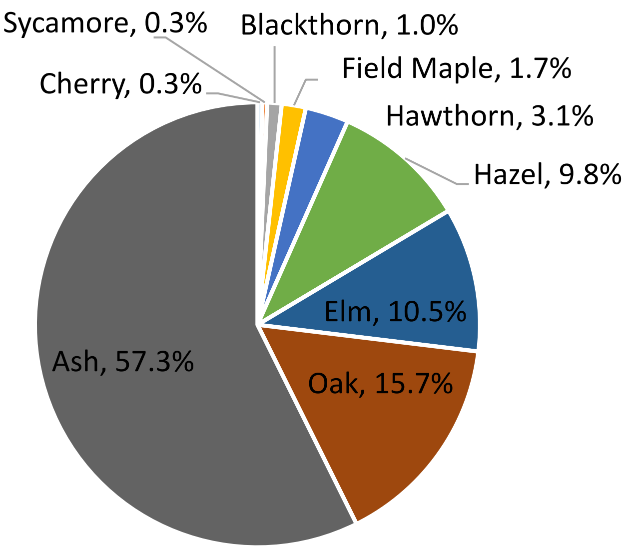

Figure 4a. Estimated species composition of the canopy / standard trees within council owned ancient woodlands in Peterborough.

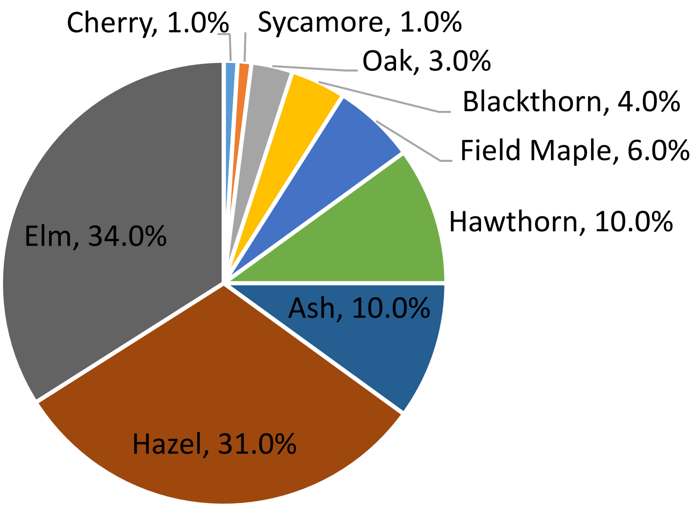

Figure 4b. Estimated species composition of the council owned ancient woodland understorey in Peterborough.

3.2 The benefits delivered by Peterborough's tree stock

The estimated annual physical amounts, annual monetary value and present value (PV) of benefits delivered by Peterborough's tree stock are outlined in Table 2. Estimates for the single trees and tree groups are shown separately as the data for the former were based on field measurements while the latter were based on informed estimates of tree group composition and structure and will be less accurate as a result. Both single tree and tree group estimates are combined to give an overview of the total benefits delivered by the

Peterborough Council owned tree stock but these values should be interpreted with caution given the assumptions made for the tree groups, and used only as a ball park figure.

The total value of air pollution removal, carbon sequestration and avoidance of surface water runoff benefits delivered by the council owned stock of trees in Peterborough is estimated to be worth £1.26 million per year (Present Value (PV) of £38.20 million over 80 years). Each tree is estimated to deliver £5.17 worth of benefits per annum (as calculated using the single trees database only). In addition, the trees also deliver an estimated total value of £11.07 million in carbon storage. A reminder that carbon in vegetation and soil is a stock and not a benefit that is accrued over time, hence this is not an annual value (which is why it is not combined with the annual values of other benefits measured), nor can PV be calculated. A breakdown of these values by the individual benefits is given below.

Table 2: Annual physical amounts, annual monetary values and present values of the benefits delivered by Peterborough's public tree stock.

Benefit	Annual physical amount			Annual monetary value (£)			Present value (£)		
	Single trees	Tree groups	Combined	Single trees	Tree groups	Combined	Single trees	Tree groups	Combined
Pollution removal (t)									
CO	0.14	0.80	0.94	137	785	922			
NO_2	2.80	15.80	18.60	62,071	350,242	412,313			
O_3	5.14	29.37	34.51	7,314	41,703	49,017			
$PM_{2.5}$	0.36	1.97	2.33	22,043	120,790	142,833			
SO_2	0.001	0.01	0.01	2	15	17			
Total	8.43	47.95	56.38	91,566	513,536	605,102	2,767,364	15,520,345	18,287,709
Carbon storage (t)[a]	12,416	33,339	45,755	3,004,699	8,068,010	11,072,709	n/a	n/a	n/a
Carbon sequestration (t)	325	1,734	2,059	78,594	419,677	498,271	2,375,318	12,683,690	15,059,008
Avoided runoff (m^3)	15,371	80,249	95,620	26,054	134,498	160,552	787,417	4,064,869	4,852,286
TOTAL (excl. carbon storage)[a]				196,215	1,067,711	1,263,926	5,930,099	32,268,904	38,199,003

[a] *Carbon storage is not an annual benefit accrued over time but a stock. The amount given here is therefore not an annual value but a total value. A present value cannot be calculated for this stock.*

Air pollution removal

Peterborough's public trees are estimated to remove a total of 58 tonnes of pollutants per year, providing annual benefits worth an estimated £605,102 (PV of £18.29M). The trees had the greatest impact on ozone (O_3), removing an estimated 35 tonnes per year (£49,017 per year), followed by approximately 19 tonnes per year of nitrous oxide (NO_2) which had the greatest associated value (£412,313 per year). The monetary value associated with particulate matter removal (PM2.5) was also high, providing benefits worth £142,833 per year (estimated removal of roughly 2 tonnes per year). Though the trees also contribute to removal of carbon monoxide (CO) and sulphur dioxide (SO_2), the concentration of these pollutants in Peterborough was low and so there is little economic impact of these benefits, especially sulphur dioxide (annual value of £922 for carbon monoxide and £17 for sulphur dioxide). i-Tree Eco accounts for emissions of pollutants from trees in its calculations, so even though some individual trees may be contributing to air pollution, the net effect of Peterborough's trees is shown to be of pollution removal. On average, each tree contributes an estimated £2.41 per year in terms of air pollution removal benefits (calculated using the single trees dataset only).

Carbon storage and sequestration

Peterborough's public trees are estimated to be responsible for the storage of 45,755 tonnes of carbon with an associated value of £11.07M. Peterborough's trees are estimated to sequester 2,059 tonnes of carbon per year (or 7,550 tonnes of CO_2), worth £498,271 annually (PV £15.06M). For comparison, 9,525 tonnes of CO_2 were emitted from properties that Peterborough City Council own and from street lighting in the year 2017-18. This means that the council owned tree stock is offsetting 79.3% of the council's own emissions. Alternatively, this is equivalent to the annual emissions of 3,881 cars (based on UK average mileage of 12,714 km per year and average emissions of 153g of CO_2 per km), which is approximately 4.6% of the total number of cars in the Peterborough local authority area.

Avoided surface water runoff

Peterborough's trees are estimated to reduce surface water runoff by 95,620 cubic metres per year, with an associated value of £160,552 (PV £4.9M). This is equivalent to the water from 38 Olympic sized swimming pools not entering the drainage system each year.

Benefit delivery by ward

The total estimated annual value of carbon sequestration and avoided surface water runoff for each ward within Peterborough is given in Table 3. Pollution removal values are not included here as it is not possible to get the breakdown by ward in i-Tree. Carbon storage is presented separately in Table 4 as this is not an annual value but a total value of the stock.

The ward contributing the most benefits in terms of monetary value per annum from its trees, despite its relatively small size (311ha), is Bretton, worth an estimated total of £124,807 per year. The value derived from the benefits delivered by single trees was highest in this ward (£15,183 per year). Bretton is also home to the largest area of ancient woodland in Peterborough which plays a significant role in the contribution of tree group benefits in this ward (worth £109,624 per annum), second only to tree group benefits in Hargate and Hempsted. Barnack, the third largest ward (4,515 ha), had the lowest value of benefits derived from public trees, with an estimated annual value of £1,174. Unsurprisingly, carbon storage is also greatest in Bretton (estimated value of £2.24M) and lowest in Barnack (estimated value of £33,298).

Table 3: Total annual monetary values of carbon sequestration and avoidance of surface water runoff benefits delivered by public trees in the wards of Peterborough.

Ward	Ward area (ha)	Benefit value (£/year)		
		Single trees	Tree groups	Combined
Barnack	4,515	1,010	164	1,174
Bretton	311	15,183	109,624	124,807
Central	283	6,551	4,359	10,910
Dogsthorpe	228	6,501	17,872	24,373
East	842	4,248	29,390	33,638
Eye, Thorney and Newborough	13,307	6,678	25,230	31,908
Fletton and Stanground	705	2,395	7,803	10,198
Fletton and Woodston	318	4,081	13,673	17,754
Glinton and Castor	5,267	5,591	20,974	26,565
Gunthorpe	384	1,532	23,030	24,562
Hampton Vale	1,149	591	21,769	22,360
Hargate and Hempsted	280	800	72,423	73,223
North	221	3,350	5,328	8,678
Orton Longueville	464	8,429	43,720	52,149
Orton Waterville	688	6,645	57,409	64,054
Park	202	4,021	14	4,035
Paston and Walton	248	5,094	13,171	18,265
Ravensthorpe	326	8,112	10,269	18,381
Stanground South	538	2,221	11,306	13,527
Werrington	460	8,651	37,752	46,403
West	387	2,246	25,903	28,149
Wittering	3,219	720	2,994	3,714
TOTAL	**34,342**	**104,650**	**554,177**	**658,827**

**Rounding errors result in differences for breakdown by Ward compared to the overall summary.*

Table 4: Total monetary values of carbon storage benefits delivered by public trees in the wards of Peterborough.

Ward	Ward area (ha)	Carbon storage (£/year)		
		Single trees	Tree groups	Combined
Barnack	4,515	31,027	2,271	33,298
Bretton	311	372,627	1,865,182	2,237,809
Central	283	236,795	60,446	297,241
Dogsthorpe	228	181,834	247,852	429,686
East	842	122,336	407,585	529,921
Eye, Thorney and Newborough	13,307	297,028	349,902	646,930
Fletton and Stanground	705	78,309	108,217	186,526
Fletton and Woodston	318	117,167	189,618	306,785
Glinton and Castor	5,267	229,687	328,526	558,213
Gunthorpe	384	43,594	319,385	362,979
Hampton Vale	1,149	9,005	301,893	310,898
Hargate and Hempsted	280	12,669	1,004,379	1,017,048
North	221	81,186	73,885	155,071
Orton Longueville	464	204,790	606,327	811,117
Orton Waterville	688	143,141	796,171	939,312
Park	202	110,635	191	110,826
Paston and Walton	248	174,501	182,666	357,167
Ravensthorpe	326	198,266	142,410	340,676
Stanground South	538	76,162	156,793	232,955
Werrington	460	175,041	523,557	698,598
West	387	87,231	359,237	446,468
Wittering	3,219	21,666	41,517	63,183
TOTAL	**34,342**	**3,004,697**	**8,068,010**	**11,072,707**

**Rounding errors result in differences for breakdown by Ward compared to the overall summary.*

CAVAT amenity values

The CAVAT values are an estimate of tree amenity value that takes human population density into account. The total estimated CAVAT value for Peterborough's trees is £2.86 billion (Table 5). The single tree contribution to this total is £5.64 million (£14,850 per tree) while the remaining £2.29 billion is from the tree groups. The tree group value should be interpreted with caution as CAVAT was designed for use on single trees with no adjustment possible to account for the number of trees in a group, which may influence the individual amenity value of each tree within a group.

The amenity value of trees varies considerably between Peterborough's wards ranging from £556.91 million in Bretton to £5.67 million in Barnack. The amenity value of trees in Bretton is much larger than other wards, with trees in Hargate and Hempsted, the second largest value, worth £266.14 million. This is driven primarily by the nearly 18ha of ancient woodland in the Bretton Ward.

Table 5: Amenity values of Peterborough's public tree stock calculated using the CAVAT quick method and broken down by ward.

Ward	CAVAT value (£M)		
	Single trees	Tree groups	Combined
Barnack	5.08	0.60	5.67
Bretton	68.64	488.27	556.91
Central	43.29	19.84	63.13
Dogsthorpe	39.10	97.61	136.71
East	18.38	107.01	125.39
Eye, Thorney and Newborough	48.52	91.87	140.39
Fletton and Stanground	12.07	28.41	40.48
Fletton and Woodston	21.90	62.23	84.13
Glinton and Castor	36.55	75.44	111.99
Gunthorpe	8.45	104.82	113.27
Hampton Vale	1.64	79.26	80.90
Hargate and Hempsted	2.44	263.70	266.14
North	21.39	29.10	50.48
Orton Longueville	41.70	198.99	240.69
Orton Waterville	24.26	209.04	233.29
Park	43.60	0.08	43.68
Paston and Walton	27.44	71.94	99.38
Ravensthorpe	37.44	46.74	84.18
Stanground South	10.25	41.17	51.42
Werrington	37.55	171.83	209.37
West	10.60	94.32	104.92
Wittering	3.26	10.90	14.16
TOTAL	**563.55**	**2,293.14**	**2,856.70**

4. Conclusions

Valuation of benefits provided by the council owned tree stock of Peterborough has been successfully applied using both i-Tree Eco and the CAVAT method. The results have shown that the trees in Peterborough are providing significant benefits to society in the form of public services and how these vary between wards. This approach is useful at highlighting these values which may otherwise remain hidden and provide a basis for managing trees as a public asset rather than a liability. A number of assumptions and estimates have, however, been used in the calculation of these benefits (discussed further below) and their associated values and should, therefore, be interpreted with caution.

The amenity value of Peterborough's trees was significantly larger than the value of all other benefits (total CAVAT value of £2.86 billion compared to a PV of £38.20 million for all other benefits combined. This is common in other studies that have used both i-Tree and CAVAT analysis of urban trees (Rouquette & Holt 2017) and highlights the importance of amenity value. Air pollution removal was the second most valuable benefit delivered by Peterborough's trees (PV of 18.29 million), followed by carbon sequestration (PV of 15.06 million), and reduced surface water runoff valued at £4.9 million. The per tree value of air pollution removal, carbon sequestration and surface water runoff benefits, although relatively small on a per tree basis (£5.17 per year), scale up to deliver significant benefits on a city-wide basis. Per tree values of pollution removal, carbon sequestration and avoided surface water runoff compare to the averages reported in a review of studies conducted using i-Tree (Rouquette & Holt 2017), and are, on average, a little higher (£2.41 per tree per annum compared to £1.58 for air pollution, £2.07 compared to £1.20 for carbon sequestration and £0.69 compared to £0.44 for runoff). Variations between studies are to be expected given different tree composition and structure of each city's tree stock as well as variable prices/costs used in the valuation of benefits delivered.

The CAVAT values, however, are considerably higher than the average from this same review of studies (£14,850 per tree based on the single trees database, compared to £2,000 per tree). This higher valuation of amenity value is most likely because we used a simpler method of calculation due to the lack of available data. Previous studies that have used the CAVAT method have incorporated accessibility of trees into calculations, with lower valuation attributed to trees considered to be less accessible. Trees in residential areas, for example, were downweighted to 40% accessibility. Functionality scores were also downweighted depending on various factors such as likely management intensity. We did not account for accessibility or this additional functionality measure in the present study, which could account for the comparatively higher amenity values we obtained. The amenity value of Peterborough's tree stock could therefore be an overestimate, but even when additional factors have been taken into account in other studies, amenity value is always much higher than the value of the other services measured. Furthermore, a study of Ealing Council's tree stock, which did take both accessibility and functionality into account using the CAVAT method, reported amenity values higher than those of Peterborough's trees (£25,000 per tree per year, Rogers et al. 2018). Finally, the CAVAT method does not allow for adjustments to the valuation to be made according to whether trees are stood by themselves or in a group, which is likely to lead to an overestimation of amenity value for our tree groups.

Many assumptions had to be made for the calculation of the tree groups and the resulting estimates of the benefits they deliver. Furthermore, additional information that can help improve the estimates calculated by i-Tree Eco were not available. The results presented in this report should therefore be treated as ball park figures.

What we have presented represents a snapshot in time of Peterborough's tree resource. The trees are a dynamic asset with, for example, some trees living less than the 80 years over which time present values were calculated and others living much longer, and some trees being replaced. The valuation can act as a baseline for observing how this asset changes through time.

It is important to note that the valuation conducted here represents only some of the benefits delivered by urban trees, as only a small number of the benefits provided by trees are captured within i-Tree and through use of the CAVAT method. Many other environmental, social and ecological benefits such as reduction in noise pollution, temperature regulation and associated reductions in energy consumption, health and well-being benefits and habitat for wildlife are also provided by urban trees. Thus the total value of benefits provided by Peterborough's trees is likely to be much greater than the figures presented here. Furthermore, Peterborough's trees represent a relatively young tree stock and the benefits delivered from these trees and their associated value will generally increase as the trees mature.

The valuation will also slightly underestimate the full value of the Peterborough tree stock as not all council owned trees are currently included in the inventory of single trees or tree groups. Although the vast majority of trees in the more urban areas are included, there are some gaps in some of the rural wards. This was checked by examining a GIS layer of all tree cover against a layer that identifies all council owned land. Please note, also, that we have only assessed council owned trees. These are thought to represent less than 15% of the total tree stock across the local authority area, although in several of the wards towards the urban centre, more than 50% of the total tree stock is council owned. This means that the benefits calculated in this report represent only a relatively small proportion of the total benefits provided by trees across Peterborough.

Peterborough's individual tree stock is relatively diverse at present, with no single species taking up more than 10% of the stock. However, the tree groups are less diverse, with a large proprotion made up of ash, and overall diversity is much lower. This is a potential problem, as new pests and diseases are appearing regularly, with the potential to devastate certain species. Ash, in particular, is susceptible to ash dieback, which only appeared in this country a few years ago, and is starting to have a major impact on this species across the country. If ash dieback were to become common in Peterborough, this would lead to the potential destruction of large numbers of Peterborough's trees, which in turn would lead to a major loss of the benefits described in this report. It is important therefore, that

Peterborough Council adopts a policy of replacing all trees that are removed, and plants a wide variety of different species to reduce the impact of any one particular disease.

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Annex 1: i-Tree Eco v6 benefit model methods

i-tree Eco v6 is designed to use standardized field data along with local hourly air pollution and meteorological data to quantify urban forest structure, multiple benefits delivered by the trees and their associated value. Specifically, i-Tree Eco can provide assessments of:

- Urban forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year.
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power sources.
- 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.

Effects of trees on building energy use and the potential impact of infestations by pests were not included in our analyses of Peterborough's tree stock due to lack of data.

The most recent year both meteorological and pollution data were available within i-Tree Eco for the Peterborough area was 2013, with meteorological data collected from a weather station in Wittering (less than 10 miles from Peterborough city centre).

As information on tree crown health was not available in the provided tree inventory, i-Tree Eco used a default value of 13% dieback when tree health was required in the calculation of service benefits.

Air pollution removal

Pollution removal was calculated for ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter less than 2.5 microns ($PM_{2.5}$). Air pollution removal estimates were derived from calculated hourly tree-canopy resistances for O_3, and SO_2 and NO_2 based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988; Baldocchi et al 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser 1972; Lovett 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke 1967). Recent updates (2011) to air quality modelling are based on improved leaf area index simulations and weather and pollution processing and interpolation (Hirabayashi et al 2011; Hirabayashi et al 2012; Hirabayashi 2011).

Valuation for pollutant removal was derived using the UK social damage costs (central estimates) based on avoided mortality and morbidity (Defra 2015) where figures were available (NO_2, $PM_{2.5}$ and SO_2 – inflated from 2015 prices to 2018 prices). The default i-Tree values based on US externality costs were used when UK figures were not available (CO, O_3) and converted to Sterling using the July 2018 exchange rate of £0.75 to $1. Pollution removal prices used in these analyses were £984 per metric ton (tonnes) of CO, £1,423 per metric ton of O_3, £22,168 per metric ton of NO_2, £2,060 per metric ton of SO_2, and £61,230 per metric ton of $PM_{2.5}$.

Carbon storage and sequestration

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

Carbon sequestration is the removal of carbon dioxide from the air by plants. To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree health was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x +1.

Carbon storage and carbon sequestration values were calculated by multiplying the tonnes of carbon stored by the government's non-traded central carbon price (£66 per metric tonne of CO_2, which is equivalent to £242 tonnes of carbon) in 2018 prices (BEIS 2017). The non-traded price 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, in accordance with UK best practice on carbon storage and capture valuation.

Avoided surface water runoff

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 Anglian Water charges for sewerage and water drainage (£1.70 per m^3 2018 price). This approach does not separate foul water sewerage prices from surface water drainage, thus the resulting valuation may be an overestimation. This is, however, the same approach adopted in most other i-Tree studies in the UK.

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Annex 2: CAVAT method

The Capital Asset Value for Amenity Trees (CAVAT) Quick Method as described in the user guide (Neilan 2017) was used to assess the amenity value of Peterborough's trees. CAVAT works by calculating a unit value based on the diameter of the trunk, and then adjusts this value to reflect the degree of benefit that the tree provides to the local population. This takes into account the nearby human population density, tree functionality and life expectancy. The CAVAT method uses a replacement value approach and is regularly used to set levels of compensation when trees are damaged or destroyed and provides a basis for managing trees in the UK as public assets rather than liabilities.

Specifically, the CAVAT Quick Method assigns a basic value to each tree according to its diameter at breast height (DBH) broken down into one of 16 size bands. This basic value is derived using a replacement cost approach. This basic value is then adjusted according to the population density of the urban areas of the Local Authority using the Community Tree Index (CTI) factor. For Peterborough, a separate CTI factor was applied for each ward, depending on the population density of the ward. The tree value is then multiplied by the functional value of the tree (how well the tree is performing biologically compared to what would be expected of a well-grown healthy tree of the same species and DBH). Five categories of functional value are used to classify the trees. Finally, the value is then adjusted for life expectancy of the tree to give the tree's final amenity value.

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Annex 3: Tree groups

The breakdowns of how a typical hectare of shelterbelt and ancient woodland trees were calculated are given below.

Typical hectare of shelterbelt trees

The information provided by Peterborough Council on a typical hectare of shelterbelt trees included the total number of trees, the size of these trees (broken down by the number of trees in each DBH range) and the proportion of different species. There were only three DBH ranges of trees within a typical shelterbelt area, 0-20cm, 21-40cm and 41-60 cm. In order to be able to estimate benefit delivery by these trees in i-Tree Eco and with the CAVAT method, we had to estimate the number of individual trees of each species within each DBH band as well as their height, functional value and life expectancy.

Greater DBHs are more likely from larger tree species so we devised a method to account for this when estimating the proportions of trees allocated to the three different DBH bands of trees found within the shelterbelt. We classified the tree species into three categories; small, medium and large. Trees classed as small were all allocated to the 0-20cm band. This was calculated by multiplying the proportion of trees of a small species by the total number of trees in one hectare of shelterbelt. 11.49% of shelterbelt trees, for example, are hawthorns so we multiplied this by 1164 (total number of trees) to give us 134 trees, all of which were allocated a DBH of 0-20cm.

The proportion of trees left in each DBH band once all small tree species were allocated to 0-20cm DBH was then recalculated. Trees classed as medium in size were then allocated to the DBH bands of 0-20cm and 21-40cm according to the proportion of trees in each of these two categories. 14.26% of all shelterbelt trees, for example are field maple giving a total of 166 trees within a typical hectare of shelterbelt. We multiplied the proportion of remaining trees with a DBH of 0-20cm by 166 to give us the number of field maple trees of this size. The same calculation was done using the proportion of trees with a DBH of 21-40cm to give the total number of field maples of this size.

The proportion of trees left in each DBH band was recalculated once again to account for the trees already allocated to size bands of 0-20cm and 21-40cm. The trees classed as large were then allocated to each of the three size bands according to these proportions.

Each tree species of a particular DBH band was then allocated a height using the average value for that tree species and DBH from the inventory of single trees measured in the field. All trees were allocated a life expectancy or 40-80 years and functional value of 75% as these were the median and most common values for the trees in the single tree inventory.

Ranges of DBH are used in the CAVAT method, however, a single value is required in i-Tree Eco, so we used the midpoints of each DBH range.

Typical hectare of ancient woodland

Averages from previous surveys of ancient woodland areas within Peterborough together with additional information provided by the council were used to determine the composition of a typical hectare of ancient woodland. The ancient woodlands of Peterborough contain both large standards and smaller understorey coppice trees. Each hectare contains c. 286 standards, dominated by ash and oak trees. Averages from previous surveys were used to determine the proportion of both medium and large ash and oak trees per hectare. The estimated range of DBHs typical for large and medium trees within the ancient woodlands was provided by the council. We took the centre points of these size ranges to use in subsequent analyses (medium = 40cm, large = 90cm). No information on height was available so the averages of ash and oak trees from the main dataset of single trees with the medium and large DBH ranges were used to determine height. The composition of the remaining standards was not available so the proportions of the species found in the understorey were used (see below). The larger tree species (elm, sycamore) were allocated DBHs and heights using the same approach as for ash and oak. Trees from the medium sized species (field maple) were allocated a DBH of 40cm (centre point of the medium range DBHs provided by the council) while the smaller species (blackthorn, cherry, hawthorn and hazel) were allocated a DBH of 20cm (centre point for the small range of DBHs). The average height of trees for each species with the relevant range of DBHs from the main dataset of single trees was used in subsequent analyses. Information on functional value and life expectancy was not available for the standards and so the same figures as used for the shelterbelt trees were applied.

Each hectare also contains c. 1340 coppice stems. The species composition of these trees was provided but information on DBH, height, functional value and life expectancy were unavailable. We therefore used the same proportions of DBH bands as found in the areas of shelterbelt trees and followed the same methods as described in the shelterbelt section above to allocate the number of trees of each species within the differenced DBH bands. The same approach as for the shelterbelt trees was also taken to estimate tree height with the same figures as above used for functional value and life expectancy.