The importance and value of Petersfield’s trees

Results of the 2016 i-Tree Eco survey

April 2017

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. Treeconomics and Forest Research have worked with USDA and other agencies to make the i-Tree Eco application functional for users in the United Kingdom.

Further details on i-Tree Eco and the full range of i-Tree tools for urban forest assessment can be found at: www.itreetools.org. The web site also includes many of the reports generated by the i-Tree Eco studies conducted around the world.

For further details on i-Tree Eco in the UK, on-going i-Tree Eco model developments, training workshops, or to download many of the reports on previous UK i-Tree Eco studies, visit www.trees.org.uk, www.treeconomics.co.uk or www.forestry.gov.uk/fr/itree.

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Copies of this report can be downloaded from:
https://sites.google.com/site/petersfieldtreesurvey/

Contents

Executive Summary

Trees and woodlands help to make urban living more enjoyable because they provide a range of benefits, or 'ecosystem services', to people living in and around the towns and cities they're located in. Trees improve local air quality, capture and store carbon, reduce flooding and cool urban environments. They provide a home for urban wildlife, a space for people to relax, exercise and they can support community interaction. The direct benefits to the people who live in and visit Petersfield are the focus of this report. Using a well-known and accepted assessment and evaluation model – i-Tree Eco v. 6.0 – important urban tree benefits are monetised so that the real impact of having these trees in the town can be understood in financial terms. This should aid in development of policies and practices to support tree management in the town, and the identification of appropriate resources to ensure that the benefits from trees are maintained and enhanced.

The way that trees are managed, for example in choice of species or size that trees are allowed to grow, will affect the nature and size of tree ecosystem services. So gaining an accurate picture of the species, size structure, composition and distribution of trees is an important first step to understanding how they can deliver these services. And by measuring these attributes, the monetary value of some of the most significant ecosystem services can be calculated.

The 2016 i-Tree Eco survey in Petersfield has provided detailed information on tree structure, species composition and values in the central built up area of the town and the surrounding countryside within the parish boundary. The replacement cost and amenity asset values are measured in millions of pounds. The survey also demonstrates that residents living in and around Petersfield benefit significantly from ecosystem services provided by trees. In terms of avoided water runoff, carbon sequestration and the removal of two types of air pollutants alone, we estimate that Petersfield's tree population provides citizens with ecosystem services worth nearly £75,000 each year.

These values are very significant but they exclude the many ecosystem services provided by trees that are not currently assessed by i-Tree Eco, including the value as wildlife habitat, the role in moderating local air temperatures and in reducing noise pollution. Hence, the value of the ecosystem services provided is a *conservative estimate*.

The 2016 survey captures a snapshot-in-time. It cannot consider how Petersfield's trees have changed over time or the reasons for this change. However, it does start to provide the means to make informed decisions on how the structure and composition of urban trees and woodlands in Petersfield should change in the future and how to ensure that the tree population can be made resilient to the effects of the changing climate and to other threats such as pests and diseases.

The survey was funded by The Petersfield Society and South Downs National Park Authority, with substantial support from Forest Research (the research agency of the Forestry Commission) and East Hants District Council. It was kindly carried out by volunteers organised through The Petersfield Society.

Petersfield (parish) i-Tree Eco Headline Facts and Figures

Total number of trees (estimate)	60,570
Total tree canopy cover	15.1%
Total shrub (including hedgerow) cover	5.7%
Top three most common species: urban centre	oak, Leyland cypress, ash
Top three most common species: parish total	oak, ash, elm
Proportion of small, medium, large trees (by dbh)	51.4%, 41.2%, 7.4%

Values

Air pollution removal (trees and shrubs)	6.43 tonnes (per annum)	8 kg per ha
Carbon storage	18,260 tonnes	23 tonnes per ha
Net C sequestration	580 tonnes per annum	724 kg per ha
Avoided runoff	12,778,890 litres (per annum)	15,954 litres per ha
Replacement cost	£50.7 million (Structural value)	
Amenity asset value	£498 million (CAVAT)	£8,221 per tree
Total annual benefit	£75,000 (air pollution removal, carbon storage and avoided runoff only)	

Results

In 2016, Petersfield parish:

- had over **60,570 trees (over 7 cm DBH)**, resulting in an average **urban tree density of 76 trees per hectare**, this is below existing estimates for some other towns and cities in the UK;
- had a **15.1% urban tree cover**, equal to an area of 120 ha. The trees were primarily found in **residential land, parks** and on **agricultural land** in the surrounding countryside within the parish boundary;
- included 69 tree species recorded across eight land use categories;
- had **oak, ash and elm** as the top three tree species across the parish as a whole, with Leyland cypress of additional prominence in the built-up area.

Petersfield's trees:

- intercepted an estimated **12.8 million litres of water** every year, equivalent to an estimated **£17,205** in sewerage charges avoided annually, or nearly **£425,000** if the contribution the trees make is discounted over a 50 year period;
- remove an estimated **4.4 tonnes of airborne pollutants** each year. The removal of just two of these is worth **£20,158** in damage costs annually, or nearly **£498,000** discounted over a 50 year period;
- remove an estimated **580 tonnes of carbon** from the atmosphere each year, this amount of carbon is estimated to be worth **nearly £132,000 annually**;
- store an estimated **18,260 tonnes of carbon**, this amount of carbon is estimated to be **worth nearly £4.22 million** in 2016 and represents a capitalised value of more than **£10.5 million** (over a 50 year period);
- had a **replacement value** of **£50.7 million;**
- had an **amenity asset value** of **£498 million.**

Conclusions

- Using volunteer surveyors, two i-Tree Eco surveys of Petersfield have been successfully executed. Valuable datasets have been built which describe the nature and condition of Petersfield's trees.
- Species mix in Petersfield's urban tree population is quite diverse. However, the population is dominated by several tree species which are very vulnerable to devastating pests and diseases. It is estimated that up to 15% of Petersfield's trees may die in the next five years. The population should therefore be further diversified to build resilience to the threats posed by emerging pests and diseases and climate change and to improve the range of ecological benefits that these urban trees provide to the people of Petersfield.
- The condition of Petersfield's trees is generally high but poorer in the built up area compared to the surrounding countryside. The health of street trees in the Conservation Area is generally less than desirable. It suggests that future tree planting in the built environment should be based on 'Right tree in the Right place' principles. In addition, sufficient soil resources should be made accessible to the growing tree.
- Petersfield's trees should be managed to increase the number and diversity of mature large stature trees; these are currently poorly represented yet provide proportionally more ecosystem services than small stature trees. In particular, large trees should be protected from premature felling, through appropriate planning.
- The report establishes the potential of urban trees to support and mitigate emerging health priorities associated with lifestyle and urban air pollution. The demonstration of direct benefits from the urban tree population needs to be aligned to strategic town planning to maximise these benefits.
- Of the trees recorded, a significant proportion (c. 35%) were under private management. An important resource for the town, these are outside direct control and vulnerable to unmonitored change.
- A management strategy for Petersfield's public urban trees and woodland areas is required – it should contain a minimum 20-year vision and be reviewed and updated every five years. A tree canopy cover of at least 20%, as recently recommended for England's towns and cities[1], could be achieved if an appropriate strategy and Action Plan were put in place.

1. Introduction

Trees are a vital part of the Green Infrastructure[a] of a town or city. They soften the harshness of the built environment, provide amenity for residents and visitors and provide connections to the natural environment. Increasingly they are valued for their contribution to carbon sequestration in support of climate change mitigation, they absorb air pollutants, enhance the microclimate and reduce water run-off. And, of course, they enhance the liveability of an urban centre by elevating human health and well-being. Trees are provided and managed by both local authorities and public and private landowners. The importance of trees is recognised in the recently published Petersfield Neighbourhood Plan[2].

Despite the attributes of trees summarised above, their nature, number, density and condition are rarely catalogued robustly. In addition, the monetary values of the 'goods and services' that trees deliver to society are often ignored or considered as insignificant. However, it is difficult to provide strategic management for this resource without appropriate knowledge of the resource itself, and the relative asset value it possesses.

In 2016, strategic partners involved in tree management in Petersfield agreed that it was timely to undertake a baseline resource survey of Petersfield's trees. These partners included Petersfield Town Council, East Hants District Council (EHDC), South Downs National Park Authority (SDNPA) and the Petersfield Society. The i-Tree Eco model[3] was selected as the most appropriate for this purpose. This model has been developed by the US i-Tree Cooperative[4] over the last twenty years and has been used successfully in over 100 cities globally to evaluate and value such benefits. It has been purposely broadened for use in the UK. To date, over 16 i-Tree Eco surveys have been conducted in the UK, including London, Edinburgh, Glasgow, Wrexham, Swansea and the Tawe Catchment, Burton-upon-Trent and Southampton. i-Tree Eco is rated as fit-for-purpose for valuing UK green infrastructure by Natural England[5], the government's adviser for the natural environment in England.

The partners identified above considered that the i-Tree Eco survey should be organised and conducted by Petersfield's civic society, and the Petersfield Society[6] agreed to undertake these tasks. Implicit in this decision was the need to recruit appropriately trained volunteers to

[a] 'A network of multi-functional green space, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefits for local communities' (DCLG, 2012).

manage the project and perform the survey work – there was no significant budget to employ contractors for these roles. Forest Research, one of the lead organisations involved in developing and deploying i-Tree in Great Britain, kindly agreed to support the Petersfield project. SDNPA supported the project through the purchase of equipment and volunteer training. EHDC kindly agreed to help in identifying relevant householders in advance of fieldwork. The remainder of expenses incurred during the project, for further equipment and production of reports, has been provided by the Petersfield Society. Last but not least, the volunteers have given freely of their time; many also incurring travel costs in order to take part.

Early in the planning process, it was decided to undertake two complementary i-Tree Eco surveys, one covering the whole parish area, and embracing both public and privately managed trees. The other would concentrate on public trees in Petersfield's central Conservation Area. In this report, we present the key findings of these two i-Tree Eco surveys, undertaken during the summer of 2016.

Ecosystem Goods and Services

The Millennium Ecosystem Assessment (2005) and the UK National Ecosystem Assessment (2011) provide frameworks to examine the possible goods and services that ecosystems can deliver, according to four categories: provisioning, regulating, supporting and cultural services. The ecosystem services valued by i-Tree Eco plus the other ecosystem services considered within this report are presented in

. Quantifying and assessing the value of the services provided by Petersfield's urban trees will help raise the profile of the trees and can inform decisions that will improve human health and environmental quality.

This publication sets out the direct benefits of Petersfield's trees. It can also be used to encourage investment in the wider environment and provide the case for targeted increases to restore, repair and maintain the urban tree population and other green infrastructure community assets. The return for investment will be a faster, more transparent protection system which meets the needs of users and helps foster local communities proud of the place they live.

Table 1 shows that many of the ecosystem services provided by urban trees are not quantified or valued by i-Tree Eco. **The value of Petersfield's urban trees and woodlands presented in this report**

should therefore be recognised as a conservative estimate of the value of the full range of benefits that they provide to the residents and visitors to Petersfield.

Table 1. List of ecosystem services provided by urban trees and woodlands arranged according to the MEA categories of Provisioning, Regulating, Supporting and Cultural services. Ecosystem services considered within this report are underlined, those that are valued are also *italicised*.

Provisioning	Regulating	Supporting	Cultural
Food (e.g. nuts, berries)	Climate mitigation	Soil formation	Social cohesion
Wood	*Carbon sequestration*	Biodiversity / habitats for species	*Public amenity*
	Air pollution mitigation	Oxygen production	Education
	Water pollution mitigation		Recreation, mental and physical health
	Water protection *(stormwater treatment)*		Landscape and sense of place
	Soil protection		

It is also important to recognise that:

- the v6 i-Tree Eco model provides a snapshot-in-time picture on size, composition and condition of urban trees and woodlands. Only through comparison with follow-up i-Tree Eco studies, or studies using a comparable data collection method, can we assess how these change over time.
- i-Tree Eco requires air pollution data from a single air quality monitoring station and the data used therefore represent a town-wide average, not localised variability.
- i-Tree Eco is a useful tool providing essential baseline data required to inform management and policy making in support of the long term health and future of urban trees and woodlands, but does not of itself report on these factors.
- i-Tree Eco demonstrates which tree species and size class or classes are currently responsible for delivering which ecosystem services. Such information does not necessarily imply that these tree species

should be used in the future. Planting and management must be informed by:

- considerations specific to a location, such as soil quality, quantity and available growing space, highway considerations (e.g. sight lines);
- the aims and objectives of the planting or management scheme;
- local, regional or national policy objectives;
- current climate, with due consideration given to future climate projections;
- guidelines on species composition and size class distribution for a healthy resilient urban tree population.

Opportunities

The information in this report allows decision makers to target effort to achieve:

Social objectives:

- Policy: establish new policy to protect and expand key aspects of Petersfield's green infrastructure, including trees under both private and public ownership;
- Education and advocacy: raise the profile of Petersfield's urban trees as a key component of green infrastructure that provides many benefits and services to those who live and work in the area;
- Quality of life: provision of green space to support mental health and well-being through near nature experience.

Economic objectives:

- Asset management: manage Petersfield's urban trees as an asset, with appreciable return;
- Commerce, tourism and industry: plan for and finance expansion of canopy cover to ensure that the central role of greenspace in shaping the character of the town is retained and enhanced.

Environmental objectives:

- Climate change resilience: increase resilience by redressing imbalance in tree species mix and age composition profiles; such changes would also help create a population that is more resilient to the impacts of climate change;
- Risk management: identify risks to the tree population such as climate change or pests and diseases, and to plan accordingly.

Benefits of tree cover

Urban tree cover provides economic advantages – a report to the Mersey Forest showed that for every £1 invested in the Forest's programme, £10.20 was generated in increased Gross Value Added (GVA), social cost savings and other benefits.

Trees and urban greenspace improve public health – by improving the environment, urban green infrastructure encourage healthy lifestyles; and, asthma rates among children aged four and five years old are 25% lower for every additional 343 trees per square kilometre.

Mitigation of the urban heat island effect – trees provide shading and reduce ambient air temperature through evaporative cooling.

Trees help reduce the risk of flooding – results from Manchester University indicate that tree canopies can reduce surface water runoff by as much as 80% compared to asphalt. The trees also help improve water quality.

2. Methodology

A ***plot based method of sampling*** was used for the i-Tree Eco tree survey of Petersfield parish. For this survey, 201 plots were randomly selected across the town, 149 located in the built up area and 52 in the surrounding countryside. The recorded data from each plot were then extrapolated to statistically represent the parish as a whole. The boundaries adopted for the survey and the location of the 201 plots are presented in Figure 1.

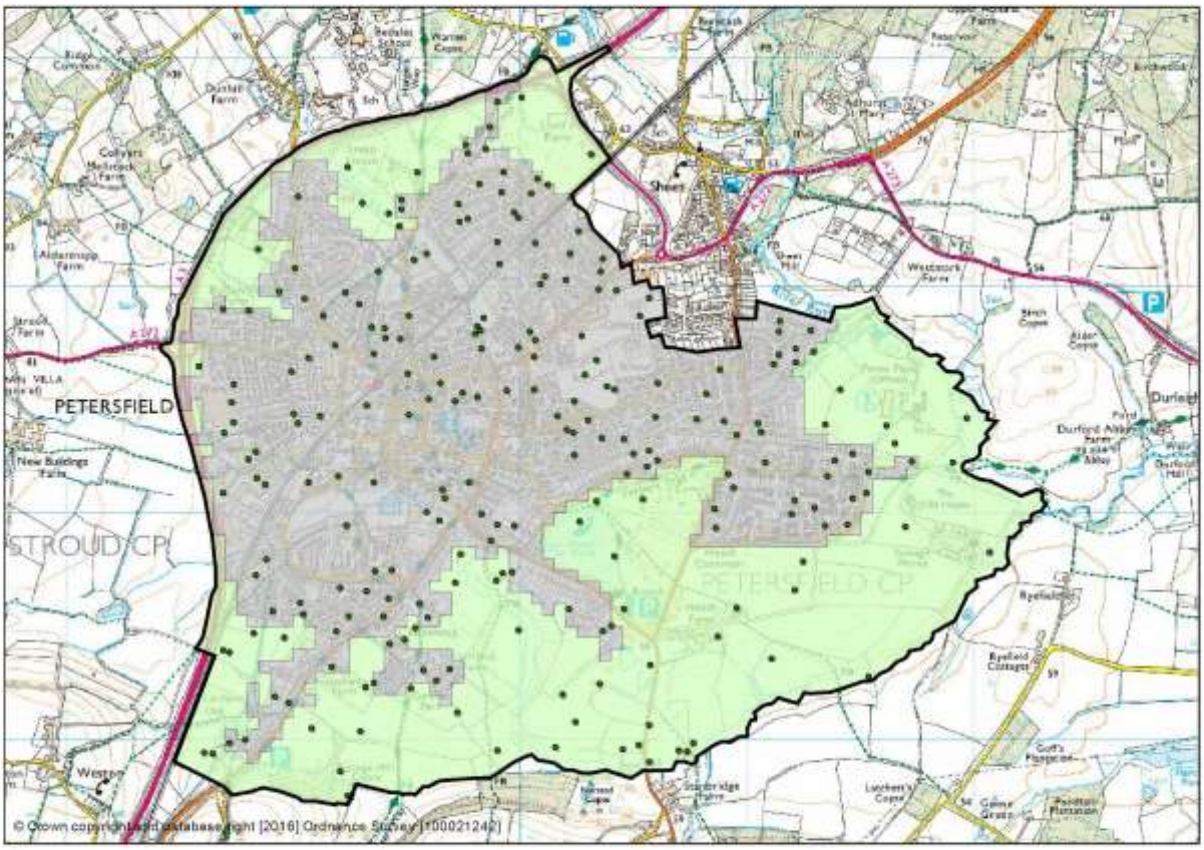

Figure 1. The Petersfield parish survey area. The randomised plots are also shown.

The total sample area was 801 ha, comprising 416 ha of built environment and 385 ha of surrounding countryside. This results in a survey point every 2.7 ha in the urban built up area and every 7.9 ha in the countryside; this is the highest plot density of any i-Tree Eco study conducted in the UK to date.

In addition to the i-Tree Eco survey of Petersfield parish, a survey of all the public trees in the designated Conservation area (Figure 2) was carried out. This involved many of the measurements taken in the parish survey but at tree scale – no plots were used.

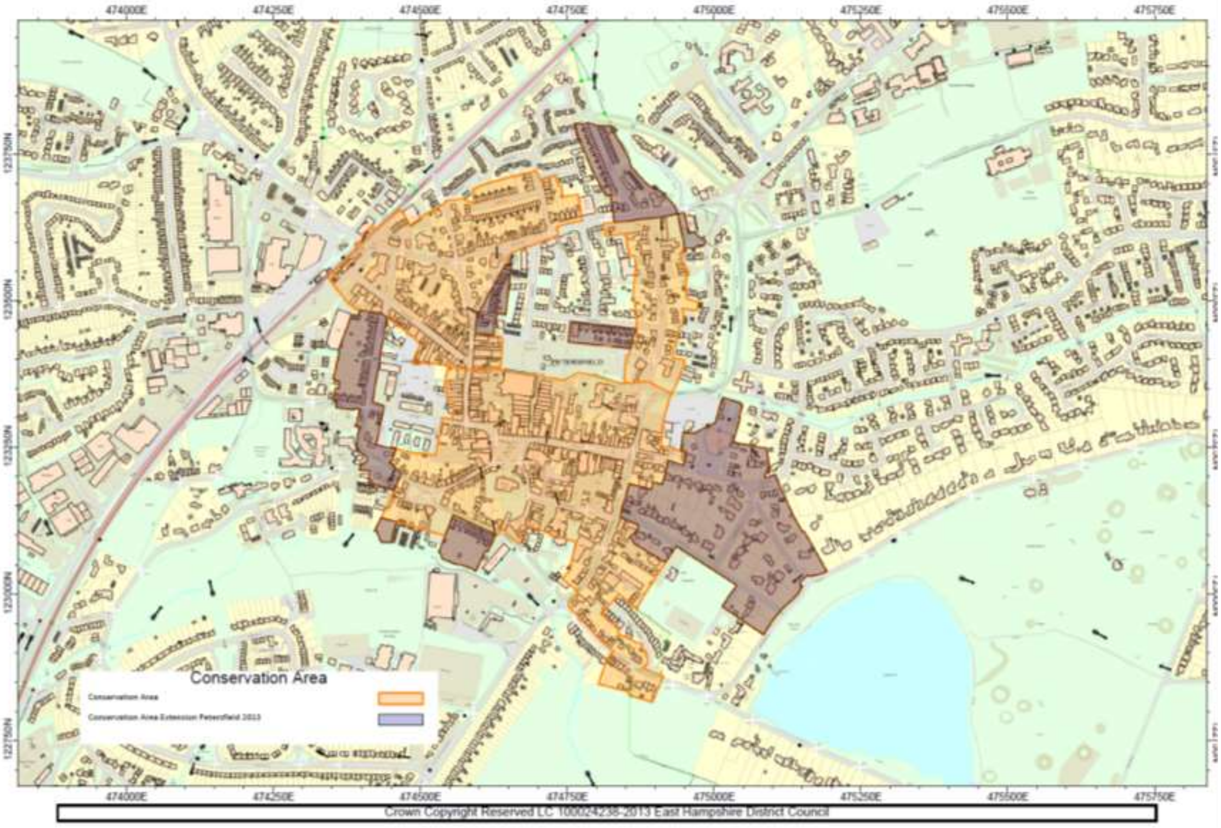

Figure 2. Petersfield Conservation Area showing 2013 extensions.

i-Tree Eco uses a standardised field collection method outlined in the i-Tree Eco Manual v6.0[7] and this was applied to each plot in the parish survey.

Each plot covered 0.04 ha (circle with radius 11.3 m) and from each was recorded:

- the type of land use, e.g. park, residential;
- the percentage distribution of cover present in the plot e.g. grass, tarmac;
- the percentage of the plot that could have trees planted in it[b];
- information about trees[c], including the
    - number of trees and their species,

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[b] For the purposes of this survey, *plantable* space was defined as an area that could be planted with little structural modification (i.e. permeable surfaces such as grass and soil) and that was not in close proximity to trees or buildings such as to hamper their growth.

[c] A *tree* is defined as a woody plant with a trunk diameter at breast height (DBH) (measured at 1.37 m (4.5 feet)) that is greater than 7 cm.

    - size of the trees including height, canopy spread and diameter at breast height (DBH) of trunk measured at 1.37 m (4.5 feet),
    - condition of the trees including the fullness of the canopy,
    - amount of light exposure the canopy receives,
    - amount of impermeable surface (e.g. tarmac) under the tree,
- Information about shrubs[d], including the
    - number of shrubs and their species (where known),
    - size and dimensions of the shrubs.

The field data were combined with local climate and air pollution data to produce estimates of ecosystem service provision. The full list of outputs generated is shown in Table 2. A summary of calculations is presented below and brought together in Table 3.

Table 2. Outputs calculated based on field collected data.

Urban tree population structure and composition	• Species diversity, canopy cover, age class, condition, importance and leaf area • Urban ground cover types • % leaf area by species
Ecosystem services	• Air pollution removal by urban trees for CO, NO_x, SO_2, O_3, $PM_{2.5}$ and a monetary value for the removal of NO_x and SO_2 • Annual carbon sequestered and monetary value • Rainfall interception and avoided sewerage charges value
Replacement costs and functional values	• Replacement cost based upon structural value (CTLA - Council of Tree and Landscape Appraisers Method) • *Replacement cost based upon amenity value (a CAVAT - Capital Asset Value for Amenity Trees - assessment)* • Current carbon storage monetary value
Habitat provision	• *Pollinating insects* • *Insect herbivores (basis for the food chain providing food for birds and mammals such as bats)*
Existing and potential insect and disease impacts	• *Acute oak decline, Asian longhorn beetle, Chalara dieback of ash, Dothistroma (red band) needle blight, Emerald ash borer, giant polypore, gypsy moth, oak processionary moth, oak wilt, Phytophthora diseases of alder, Xylella fastidiosa*

[d] A *shrub* is defined as a plant, woody or otherwise, with a total height over 1 m but a DBH of less than 7 cm.

Replacement Cost and Amenity Value

i-Tree Eco provides replacement costs for trees based on the CTLA valuation method[8]. The Capital Asset Value for Amenity Trees (CAVAT) Quick Method[9] was also used in this study. CAVAT has been developed in the UK and has been used by local authorities to support planning decisions and insurance compensation claims. CAVAT provides a value for trees in towns based on an extrapolated and adjusted replacement cost. This value relates to the replacement cost of amenity trees, rather than their worth as property per se (as per the CTLA method). Particular differences to the CTLA trunk formula method include the addition of the Community Tree Index (CTI) factor, which adjusts the CAVAT value to take account of greater amenity in areas of higher population density, using official population figures. A detailed methods section for both i-Tree Eco calculations and additional calculations, including CAVAT, is provided in Appendix I.

Pests and Diseases

Pest susceptibility was assessed using information on the number of trees within pathogen/pest target groups and the prevalence of the pest or disease in or around the Petersfield area. A risk matrix was devised for determining the potential impact of priority pests and diseases, should they become established in Petersfield's tree population. The risk matrix was adapted for use where a pest or disease targets a single genus or multiple genera.

Habitat Provision

Trees and shrubs provide valuable habitat and food for many species, from non-vascular plants, such as moss, to insects, birds and mammals. Two examples are included: i) the importance of trees/shrubs for supporting insects generally, and ii) the importance of trees/shrubs for supporting pollinators. Data are only available for some of the tree/shrub species encountered in Petersfield[10].

Table 3. Summary of Calculations.

Variable	Calculated from
Number of trees	Total number of estimated trees extrapolated from the sample plots.
Canopy cover	Total tree and shrub cover extrapolated from measurements within plots.
Identification	Most common species found, based on field observations.
Pollution removal value	Based on the UK social damage costs (UKSDC) where available: £14,646 per metric tonne NO_x (oxides of nitrogen - UKSDC), £1,956 per metric tonne SO_2 (sulphur dioxide - UKSDC),
Stormwater alleviation value	The amount of water held in the tree canopy and re-evaporated after the rainfall event (avoided runoff) and not entering the water treatment system. The value used is £1.3464 per m^3. For further details, see Appendix I
Carbon storage & sequestration values	Using a baseline year of 2016, and the respective 2016 DECC value of £63 per tCO_2e[e].
Replacement cost (direct replacement)	The value of the trees based on the physical resource itself (i.e. the cost of having to replace a tree with a similar one). The value is determined within i-Tree Eco according to the CTLA (Council of Tree and Landscape Appraisers) method, version 9.
Replacement cost (amenity valuation)	Using the Capital Asset Value for Amenity Trees (CAVAT) Quick method.

[e] CO_2e, or carbon dioxide equivalent, is a standard unit for measuring carbon footprints. The idea is to express the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of global warming.

3. Results

This chapter presents the results of the 2016 i-Tree Eco surveys of Petersfield.

Canopy cover

Based on data from the 201 sample plots, the tree **canopy cover of Petersfield parish is 15.1%.** This equates to an average density of about 76 trees per hectare. The result compares favourably to a canopy cover figure of 16.2% calculated independently using Google Maps™ imagery[1]. Using this methodology, the study analysed the tree canopy cover of 283 English towns and cities and identified a range of tree covers from 3.3 to 45.0%, with an average of 16.4%. So Petersfield's tree cover is truly an average one!

Ground cover

In 2016, ground cover in Petersfield's built-up area consisted of approximately 60% permeable materials, such as grass and soil; the remainder consisted of non-permeable surfaces such as brick, asphalt and concrete (which contribute to heating of the urban environment - see below). This value is similar to that found in the London i-Tree Eco survey[11]. Permeable surfaces reduce flash flooding and associated problems such as damage to property and infrastructure, travel disruption, and overloading sewerage systems. However, urban infilling, property extension and off-road parking all conspire to reduce permeability to rainfall, so it is likely that this figure will decrease in future. In contrast, Petersfield's surrounding countryside had over 90% permeable surfaces.

Urban Tree Populations

Numbers and species composition

Petersfield has an estimated tree population (> 7 cm DBH) of 60,570. This is a density of 76 trees per hectare, which is lower than in the Glasgow (112 trees per hectare) and Wrexham County Borough (95 trees per hectare) i-Tree Eco surveys, but slightly higher than the English average of 58 trees per hectare[12]. Roughly speaking, there are more than four trees for each person living in the town.

In the built up central area of the parish, the five most common species are oak, Leyland cypress, ash, field maple and elm whilst in the surrounding countryside, the five most common species are elm, hazel, ash, oak and holly.

Most trees in Petersfield occur in the built up area (58% of total) (Figure 3) and the majority of these are under public ownership (81% of total)[f]. This poses a significant risk for planning the urban tree population. This is because, except in the central Conservation Area, no planning permission is required for tree removal unless it is scheduled with a Tree Preservation Order.

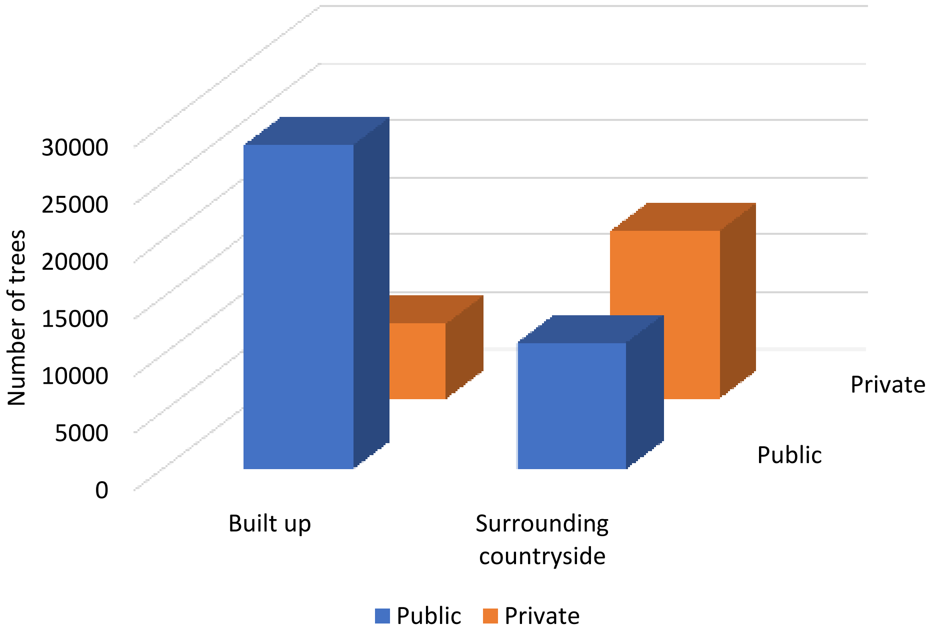


Figure 3. Estimated number of trees in the built up and countryside areas in Petersfield parish. The estimated number of public and private trees are also shown.

Species Diversity

Nearly 70 tree species were encountered during the Petersfield parish survey (for a full list, see Appendix II - Species Importance List). Of these, 45% are native to the UK.

In the Conservation area survey of street trees, 35 tree species were identified, 34% of which are of native origin (Appendix III). Table 4 lists the ten most frequent species in the built up area and the eight most frequent in the surrounding countryside.

[f] 'Private' includes the land-uses: residential, multi-residential, golf-courses, institutional, commercial, agriculture. 'Public' refers to the land-uses: park, transport, cemetery, vacant.

Table 4. The most frequent tree species in Petersfield's built-up area and surrounding countryside.

Built up	Countryside
Ash	Alder
Cherry	Ash
Cypress species (undifferentiated)	Douglas fir
Elm	Elm
Field maple	Hawthorn
Hawthorn	Hazel
Holly	Holly
Leyland cypress	Oak
Oak	
Silver birch	

A general rule of thumb for urban tree populations to be resilient to climate change and pests and diseases is that no species should exceed 10% of the population, no genus 20% and no family 30%[13]. In the Petersfield parish survey, two species exceed the 10% guideline (elm and ash), though oak (9.8%) and hazel (8.4%) approach this figure. No genus exceeded 20% frequency and no family exceeded 30%. In the Conservation area street tree survey, Callery pear and common lime both exceed the 10% guideline, and *Tilia* exceeds the 20% genus guideline.

Size Class Distribution

The size distribution of trees is important for a resilient population. Large, mature trees offer unique ecological roles not offered by small trees[14]. 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.

It is estimated that trees with a DBH <20 cm constitute 51% of the total tree population in Petersfield. In other words, more than half the town trees are small and immature. The number of trees in each DBH class then declines successively, where trees with a DBH >60 cm make up just 7.4% of the tree population (Figure 4).

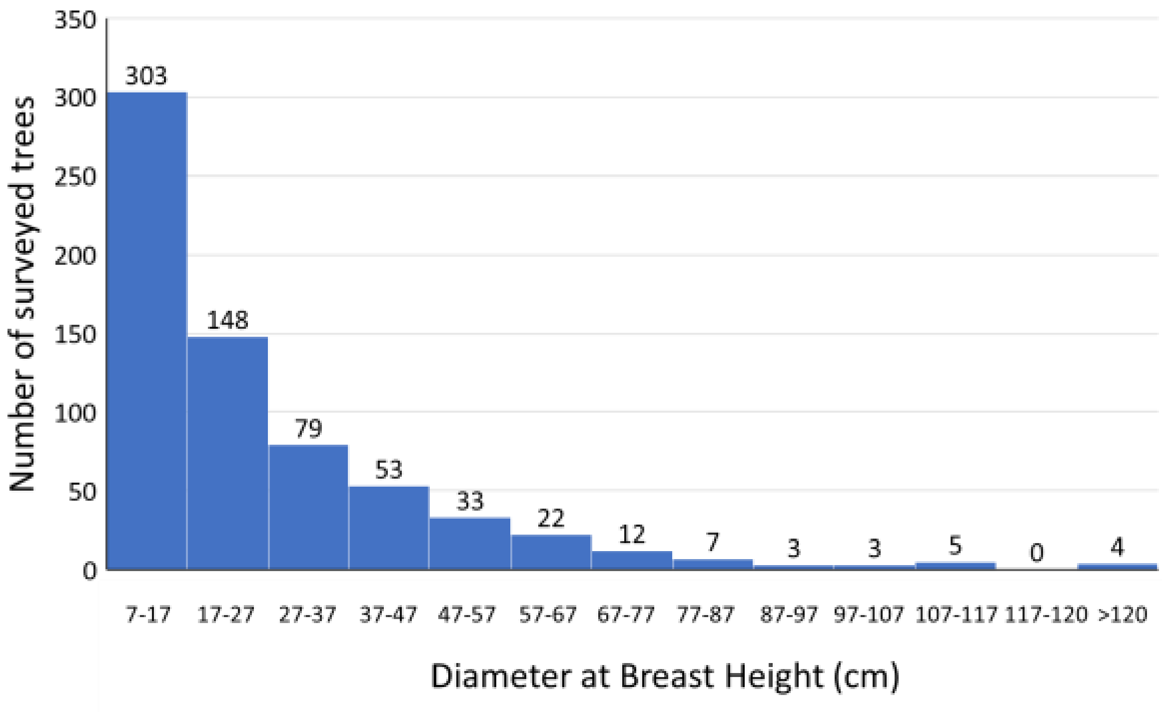


Figure 4. Histogram showing the number of surveyed trees in different trunk diameter size classes (7-17 cm DBH, 17-27 cm, etc.) for the trees surveyed in Petersfield parish.

Large trees provide more ecosystem services than small stature ones and provide more benefits compared to their costs[15]. Examination of tree species in relation to their size at maturity shows that just under one third (32%) of Petersfield's tree are defined as of natural small stature, and just over two thirds are of large stature[g]. In other words, most of the trees are capable of growing into significant trees, given appropriate care and management. Many of the small stature trees (mainly hawthorn, hazel, holly, Leyland cypress) are associated with the many hedgerows bordering properties in the town. Others such as cherry and apple are common in private gardens as ornamental and fruit trees. In Petersfield's Conservation area, just under 5% of street trees are defined as of natural small stature.

Tree Condition

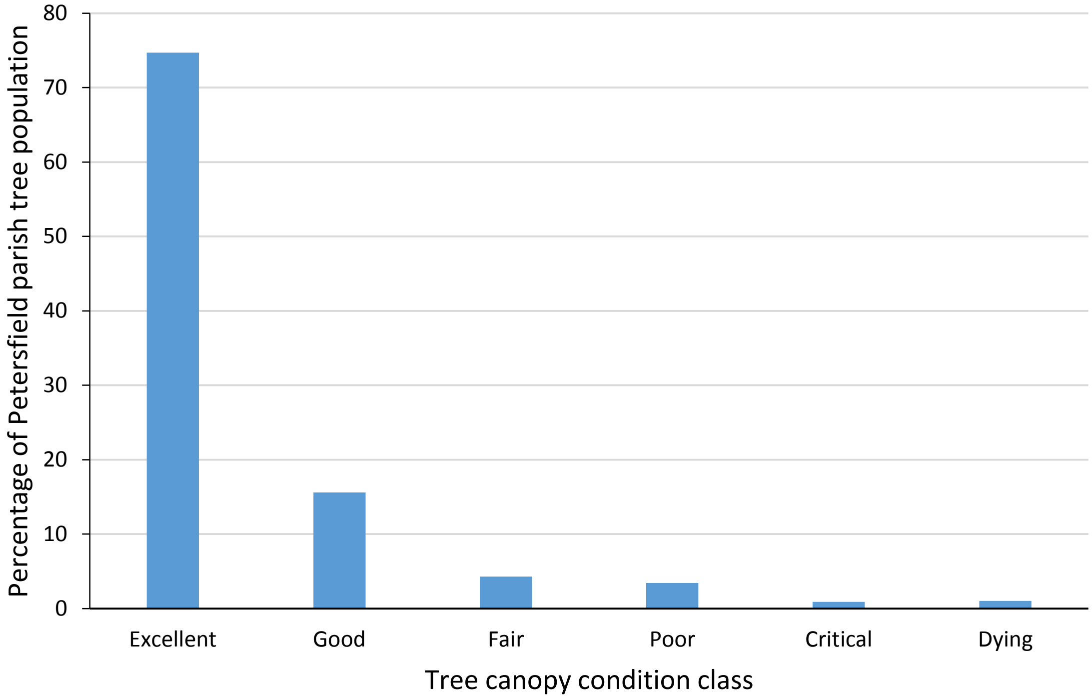
The *condition* of Petersfield's trees was generally good, with nearly 75% of trees in excellent condition, 16% in good and 4% of trees in fair condition[h] (Figure 5). Only 5% of trees was estimated as being in 'poor',

[g] Large stature trees are defined as trees that exceed 12 m height at 20 years of age and when a healthy, isolated and growing in good soil conditions; small trees are on average less than 10 m under such conditions.

[h] Conditions: excellent = less than 1% dieback; good = 1-10% dieback; fair = 11-25%; poor to dead rating = 26-100% dieback (Nowak et al. 2008). For full definition, see Appendix I.

‘critical’, or ‘dying’ conditions. Dead trees were excluded from this analysis, but very few were recorded.

Figure 5. Condition of trees encountered in Petersfield.



Condition is a useful measure of the potential prevalence of pests or diseases and the need for further enquiry. For example, follow-up surveys may be targeted at specific species where a trend is observed. Figure 6 and 7 show the condition of the top ten and eight most commonly encountered tree species in the built up and surrounding countryside components of Petersfield parish respectively. Tree condition is noticeably better in the countryside than the built up area of the town, with few concerns over the health of countryside trees. However, Figure 7 shows that oak, ash, elm and hawthorn had around 20% of trees in conditions ‘poor’ or poorer. This suggests that these species are somewhat susceptible to insect pests, disease and/or physical injury in the town. The survey also shows the comparative good health exhibited by the cypress tree family (including Leyland cypress).

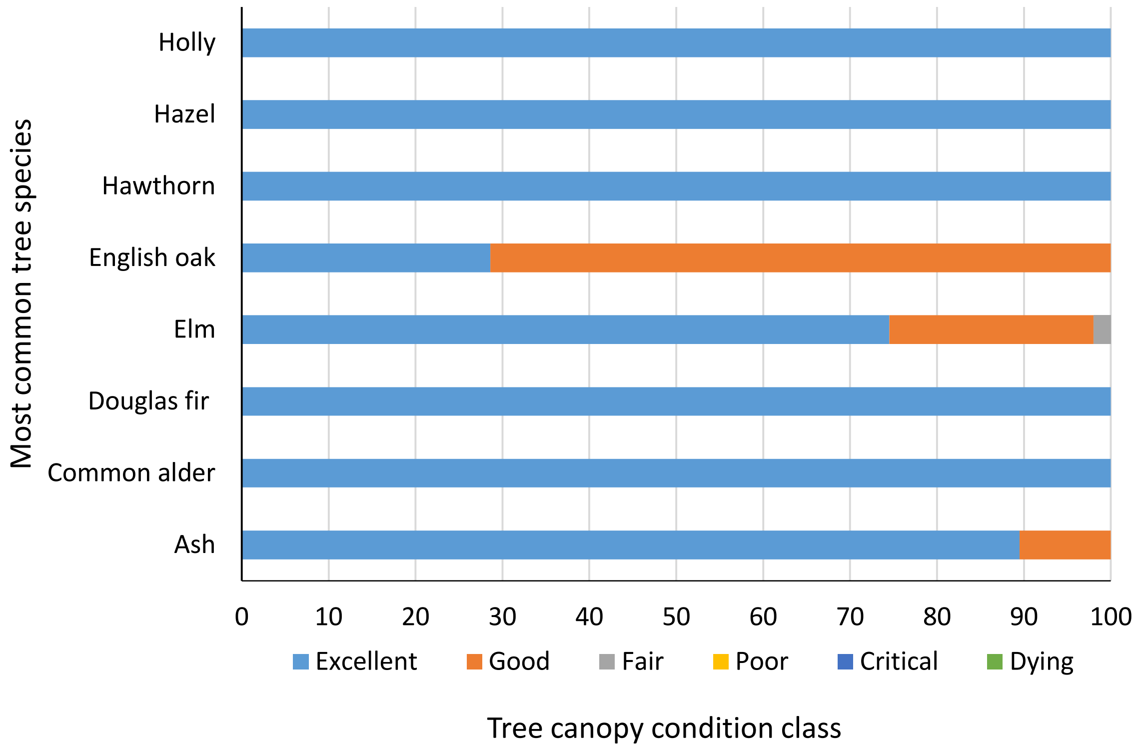


Figure 6. Condition of the top eight most commonly encountered trees in the surrounding countryside in Petersfield parish.

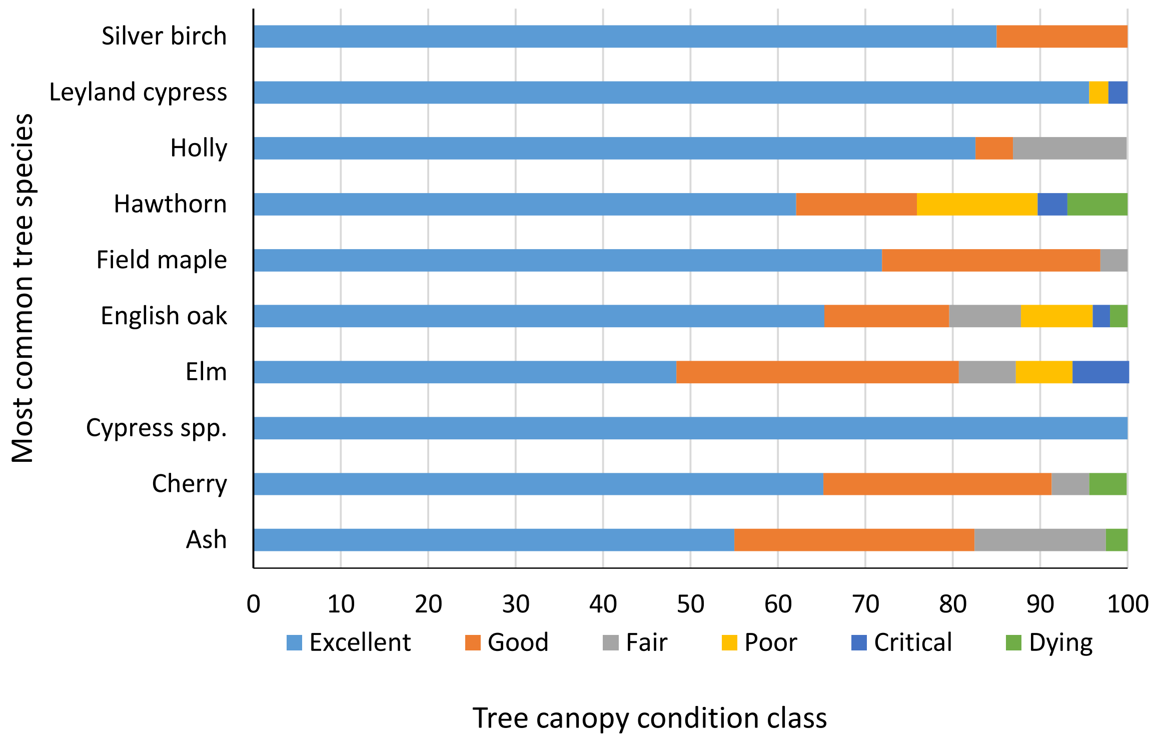


Figure 7. Condition of the top ten most commonly encountered trees in the built up area of Petersfield parish.

Leaf Area and 'Importance Value'

Leaf surface area is an indicator of the extent to which trees can provide their benefits, including the removal of pollutants from the atmosphere[16] and shade provision. The total leaf area provided by Petersfield's trees is estimated as just over 670 hectares. Oak, elm and hazel provide the most leaf surface area (21%, 10% and 10%, respectively). Some species such as oak, beech, horse chestnut and lime provide proportionately more leaf area than other species when taking tree numbers into account. In other words, they are better providers of ecosystem services, a reflection of their stature and growth habits. The percentage population and leaf area of the ten most important tree species in Petersfield is shown in Figure 8.

Importance value is calculated in i-Tree Eco as the sum of leaf-area and population size as an indication of which tree species within an urban tree population are contributing most to ecosystem service provision. Thus, trees with dense canopies and/or large leaves tend to rank highly. A list of the importance values for all 69 tree species encountered during the survey is presented in

Appendix II - Species Importance List.

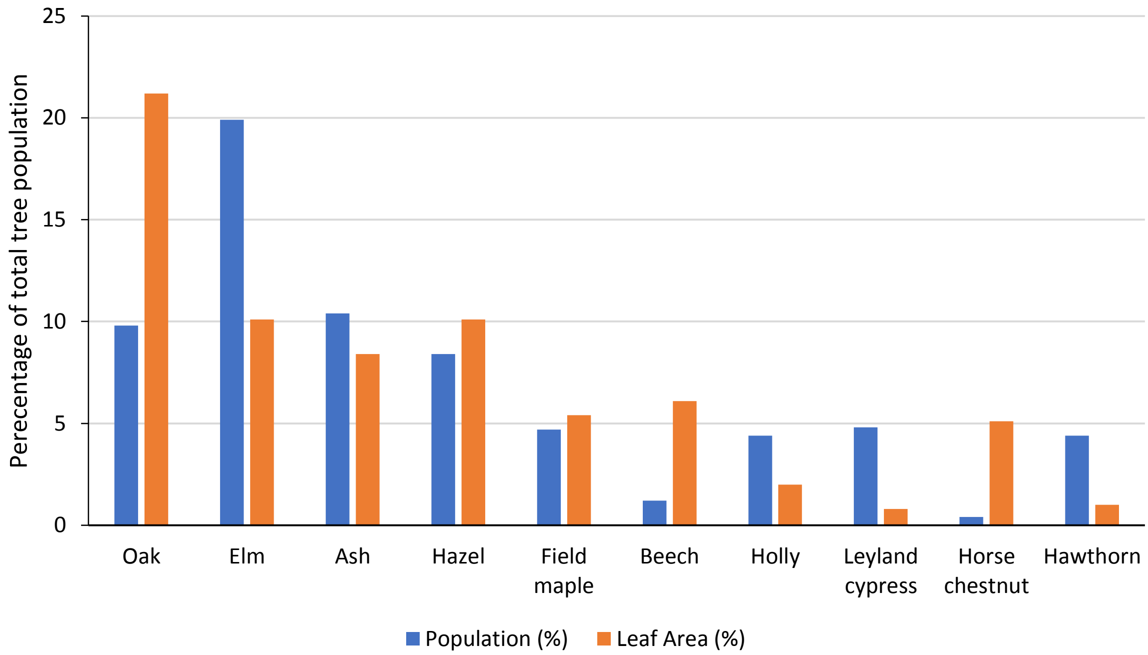


Figure 8. Percentage population and leaf area of the ten most important tree species in Petersfield.

Tree Importance Value

The scientific models that underpin i-Tree Eco reveal a direct relationship between leaf area and the provision of ecosystem services. Thus, Tree Importance Value is calculated as the sum of leaf area and tree population size and it is the most common trees which also have larger leaves or large tree canopies which rank higher in importance. Oak, elm and ash are the three most important trees in Petersfield; a consequence of their relative contributions to the total tree population and size.

Maintaining a healthy population of these trees is important for the current provision of ecosystem services to the Petersfield community. Where large stature trees are currently found it is especially important to allow them to reach and 'enjoy' maturity as far as possible. Large evergreen trees are also important for year-round provision of ecosystem services.

Replacement Cost and Amenity Value

CTLA valuation

The tree population of Petersfield parish has an estimated total replacement value of nearly £50.7 million according to the CTLA (Council of Tree and Landscaper Appraisers) valuation method. This is the cost of replacing all the trees in Petersfield should they be lost; this valuation method does not take into account the health or amenity value of trees. Table 5 gives further detail of this value relative to different parts of the parish.

Table 5. Replacement cost of trees in Petersfield by location.

Location	Replacement value
Conservation area (street trees)	£348,409
Built up area	£29,038,281
Surrounding countryside	£21,627,799
Total parish	£50,666,080

CAVAT valuation

The tree population of Petersfield has an estimated public amenity asset value of just under £498 million according to CAVAT valuation, taking into account the health of trees and their public amenity value. Oak, ash and alder had the highest overall values across the parish as a whole (Figure 9), representing nearly 50% of the total public amenity value of all the trees in the parish. The oak genus or family is by far the most important for amenity (Table 6), reflecting its generally large size around the town.

Figure 10 shows CAVAT total values for trees in each of the eight land-use classes. It demonstrates that trees in residential and parkland settings provide nearly three quarters of the total amenity value for the town. In addition, it reveals that 10% of the amenity value of the town's trees currently comes from those in so-called 'vacant' land, i.e. derelict, brownfield or land under development. There is a significant danger that much of this will be lost as such land is converted to other land-uses during development, unless appropriate safeguards are put in place.

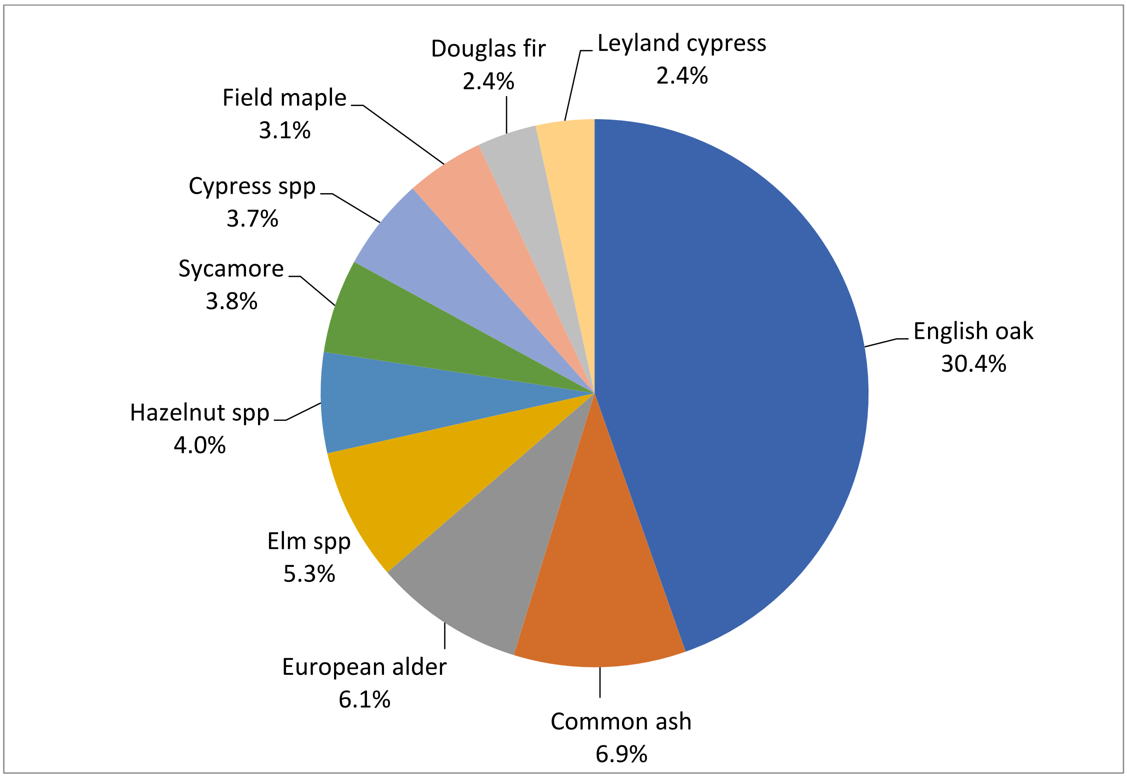


Figure 9. Ranking of the top-ten tree species in Petersfield parish according to their CAVAT valuation.

The public amenity asset value of the street trees in the Conservation area is estimated as £2.0 million. The single most valuable tree encountered in this survey was a Giant sequoia (Figure 10), calculated to have an asset value of £185,868.

Table 6. CAVAT values for the top ten trees in Petersfield parish by genus.

Genus	Number of species	Estimated total value across Petersfield (in £ millions)
Quercus (oak)	3	£164.1
Acer (maple)	5	£39.4
Fraxinus (ash)	1	£34.7
Alnus (alder)	2	£30.7
Cupressus (cypress)	unknown	£28.4
Ulmus (elm)	2	£26.5
Corylus (hazel)	1	£20.1
Tilia (lime)	3	£13.9
Pseudotsuga (silver fir)	1	£11.9
× *Cuprocyparis* (Leyland cypress)	1	£11.7
Aesculus (horse chestnut)	1	£11.6

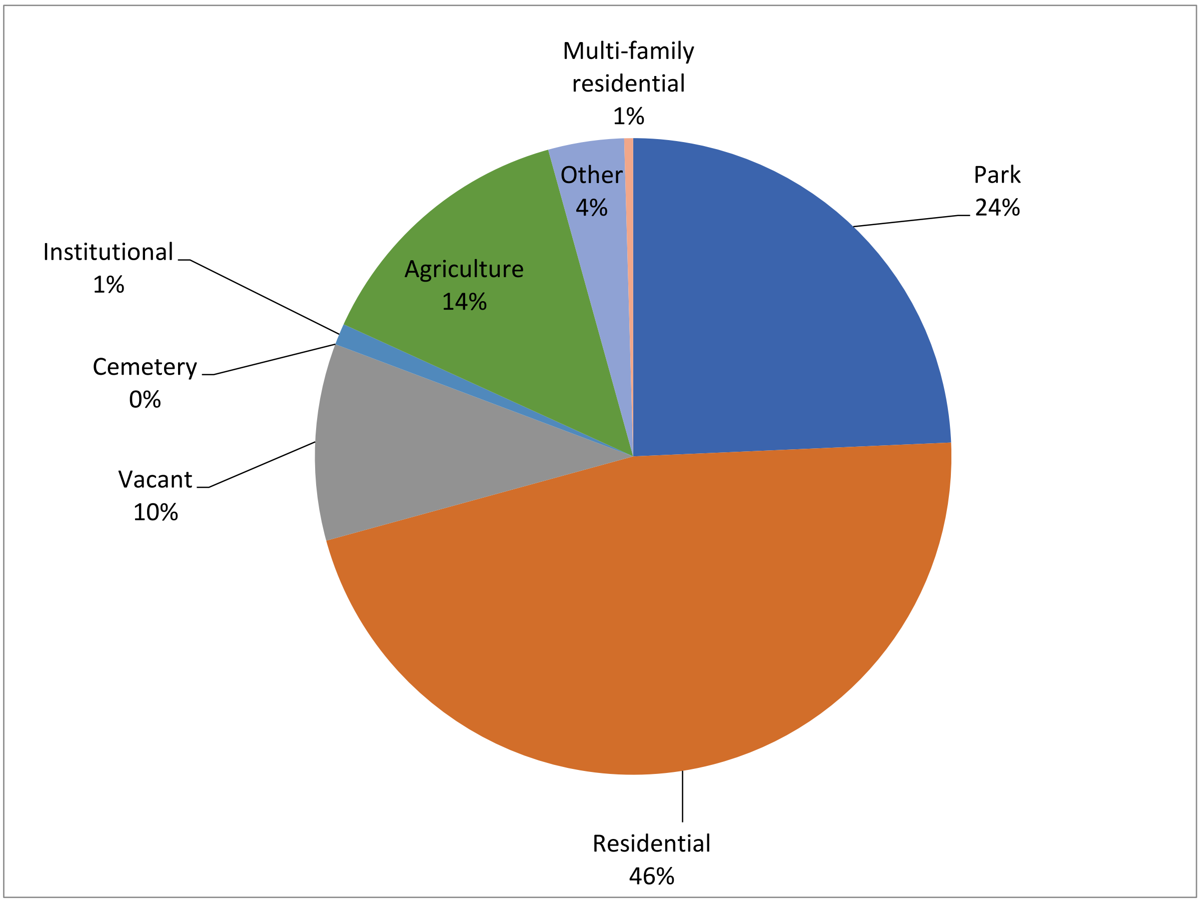


Figure 10. Percentage public amenity value held by trees in Petersfield according to land use.

Figure 11. Giant sequoia, Grenehurst Way, Petersfield. CAVAT value = £185,868.

Avoided surface water runoff

The infrastructure required to remove surface water in urban environments is costly and is out-dated in many UK towns and cities. This means that in large storm events surface water may not be removed quickly and damage to property can occur. Trees can help by intercepting rainwater, retaining it on their leaves and absorbing some into their tissues for use in respiration. The roots of trees can also increase natural drainage and this is particularly important for stormwater amelioration where the surface around the trees is permeable allowing the water to infiltrate into the soil. The trees of Petersfield intercept an estimated 12,778,890 litres of water per year, equivalent to more than 22 times the volume of Petersfield's open air pool. Based on published rates charged for sewerage[i], this saved an estimated £17,205 in avoided sewerage charges across Petersfield in 2016, or nearly £425,000 if the contribution the trees make is discounted over a 50 year period (Table 7). Figure 12

[i] Based on a Scottish Water household volumetric waste water rate of £1.3464 per m^3 – see Appendix I).

shows that large trees with dense canopies contribute the most to reducing stormwater runoff.

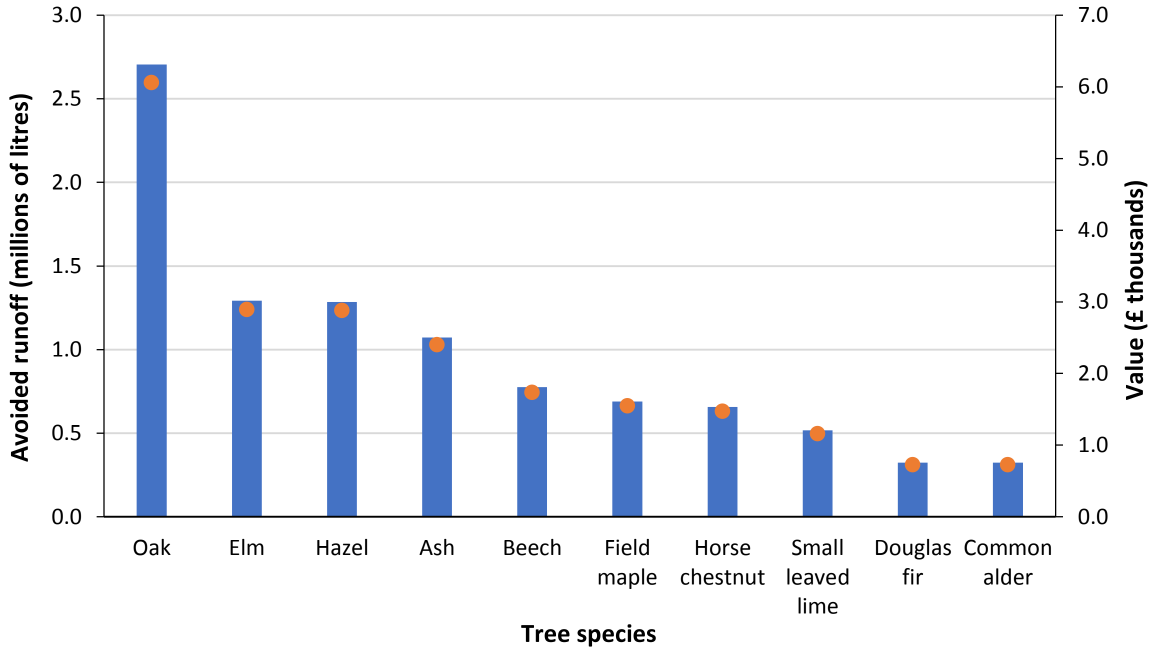


Figure 12. Avoided surface water runoff per year provided by urban trees in Petersfield (columns) and their associated value in avoided sewer costs (filled circles).

Even the trees in Petersfield's Conservation area intercept an estimated 93,640 litres of rainfall per year.

Table 7. Avoided Runoff for Trees in Petersfield.

Estimated number of trees	60,571
Leaf area	670 hectares
Avoided runoff	12,778,890 litres per year
Avoided runoff value	£17,205 (in 2016)
Discounted avoided run-off value (50 year period)	£424,848

Rainfall interception by urban trees

Trees passively intercept rainfall by retaining it on their leaves and absorbing some into their tissues. They also ease drainage into and through the soil. Trees play an important role in ameliorating the impact of stormwater and help reduce the risk of flooding. Trees with large canopies are particularly useful in this regard and across Petersfield oak, elm, hazel and ash trees provide a valuable stormwater interception service, given their relative contributions to the total number of trees in the town.

With good design, the planting of large stature trees in areas prone to flooding can complement a planning authority's strategy against flooding. Planting should occur where there is appropriate planting space and species selection must be informed by preference to the local soil, climate and hydro-geological conditions. It should take account of tolerance to flooding[17]. Planting for interception should also be complemented with planning for Sustainable Urban Drainage Systems (SUDS)[18]. SUDS are a sequence of management practices, control structures and strategies designed to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local water bodies.

Trees can provide a positive contribution to a SUDS system. The selection criteria must include all three elements of the SUDS principles: quality, quantity, and amenity (including biodiversity) in addition to the usual tree selection considerations including, for example, suitability to the location and its soil. Ultimately, however, tree use will depend on the local planning issues, water quality, water resources, architectural and landscape requirements, ecology and amenity issues, and the need to meet the requirements for the particular development.

Air Pollution Removal

Air pollution leads to a decline in human health, a reduction in the quality of ecosystems and it can damage buildings through the formation of acid rain (Table). In the United Kingdom, the Committee on the Medical Effects of Air Pollutants (COMEAP) estimated that 29,000 people die each year as a result of air pollution[19] and that the economic cost from the impacts of air pollution is £9-19 billion each year[20].

Trees and shrubs can mitigate the impacts of air pollution by directly reducing airborne pollutants. Trees absorb pollutants through their stomata, or simply intercept pollutants that are retained on the plant surface. This leads to year-long benefits, with bark continuing to intercept pollutants throughout winter[21], although at a reduced rate in comparison to summer. Plants also reduce local temperatures by providing shade and by transpiring[22], reducing the rate at which air pollutants are formed, particularly ozone[23].

Table 8. Urban pollutants, their health effects and sources.

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

Source: www.air-quality.org.uk

It is estimated that Petersfield's trees remove 4.36 tonnes of airborne pollutants per year, including NO_2, O_3, SO_2, CO and $PM_{2.5}$. If woody shrubs are included in the calculations, 6.43 tonnes of pollutants are removed each year. Ozone (O_3) and NO_2 were the pollutants removed in the highest quantities. Table 9 gives further detail of this value relative to different parts of the parish.

Table 9. Removal of air pollutants by trees in Petersfield by location.

Location	Annual amount (tonnes)
Conservation area (street trees)	0.03
Built up area	2.24
Surrounding countryside	2.12
Total parish	4.36

A monetary value can be put on the amounts of pollution removed from the atmosphere. In both the USA and the UK, pollutants are valued in terms of the damage they cause to society. However, slightly different methods are used in each country: United States Externality Costs in the US (USEC) and Social Damage Costs (SDC) in the UK (UKSDC). The UK method does not cover all airborne pollutants (Table). This is because the value of some pollutants (for example PM_{10}s) can vary depending on their emission source or because the SDC has not yet been determined by the UK Government. Using the UK system, which currently only includes NO_2 and SO_2 pollutants, £20,158 worth of pollutants are removed annually from the atmosphere (Table), or nearly £498,000 if discounted over a 50 year period.

Table 10. Amount of each pollutant removed by Petersfield's tree and shrub populations and its associated value. USEC denotes United States Externality Cost and UKSDC denotes UK Social Damage Cost.

Pollutant	Mean amount removed/tonnes per annum	US value per tonne/$	USEC value/$	UK value per tonne/£	UKSDC value/£
CO	0.1	446	387	n/a	n/a
NO_2	1.35	6,835	264,634	14,646	19,757
O_3	4.18	3,143	453,840	n/a	n/a
$PM_{2.5}$	0.58	15,734	108,320	n/a	n/a
SO_2	0.2	913	3,864	1,956	401
Total	**6.43**				**20,158**

n/a = not available

Carbon Storage

It is estimated that **Petersfield's trees store a total of 18,260 tonnes of carbon in their wood.** The built up area contributes approximately 9,950 tonnes whilst the surrounding countryside stores about 8,310 tonnes. Amongst individual species, oak stores the greatest amount and more than the next eight species put together (**Error! Reference source not found.**). Total carbon storage in Petersfield's trees is equivalent to two times the annual carbon emissions produced by its households[24,25].

Like leaf area, carbon storage depends not only on the number of trees present, but also their characteristics. In this case, the mass of a tree is important, as larger trees store more carbon in their tissues. Oak, for example, makes up an estimated 10% of Petersfield's tree population, but is responsible for over 40% of the total carbon stored in trees. In contrast, common holly makes up 4.4% of the tree population stores only 0.7% of total carbon.

The carbon in trees can be valued within the framework of the UK government's carbon valuation method[26]. This is based on the cost of the fines that would be imposed if the UK does not meet internationally agreed carbon reduction targets. Carbon values are split into two types, traded and non-traded. Traded values are only appropriate for industries covered by the European Union Emissions Trading Scheme. Tree stocks do not fall within this category so non-traded values are used instead. Within non-traded values, there are three pricing scenarios: low, central and high. These reflect the fact that carbon value could change due to external circumstances, such as fuel price.

Based on the central scenario for non-traded carbon, **it is estimated that the carbon in the current tree stock is worth nearly £4.2 million.** In 2050, this stock of carbon will be worth nearly £9.5 million. However, this value assumes no change in the structure of the urban tree population in terms of species assemblage, tree size or tree population size, and simply reflects the increased valued of non-traded carbon year-on-year to 2050. Appendix IV outlines stored carbon values from 2015 until 2065.

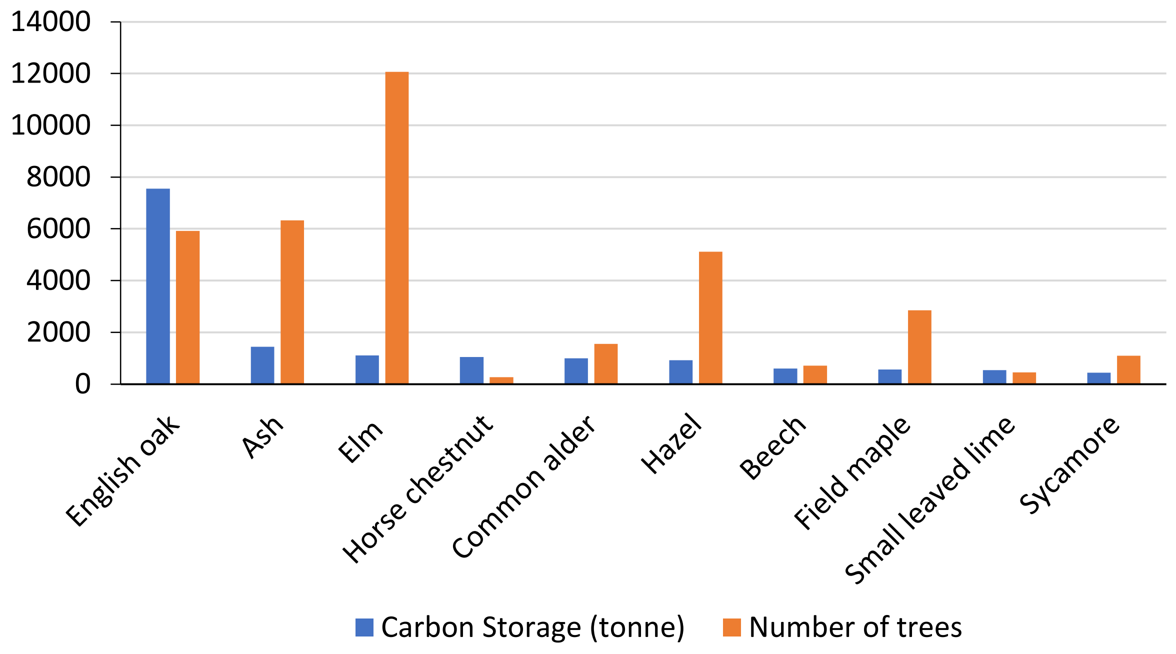


Figure 13. Amount of carbon stored in Petersfield's trees and the frequency of each species across the town. Only species with the ten highest storage rates are displayed.

Carbon Sequestration

The gross amount of carbon sequestered by trees in Petersfield each year is estimated at 580 tonnes. This amount of carbon is worth nearly £132,000. The annual net sequestration rate is equivalent to the annual emissions from 116 households[23], or nearly 2% of the total number of households in Petersfield[24].

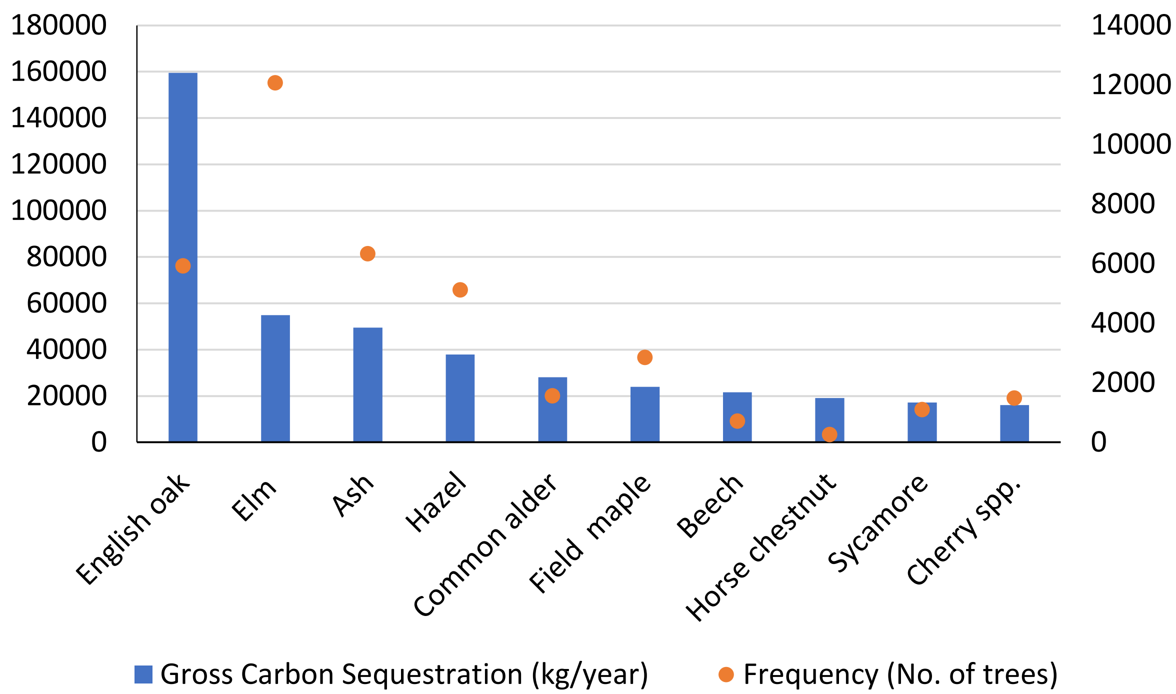


Figure 14. Carbon sequestered per year by the ten tree species with highest rates. The number of each species as a percentage of total number of trees is also shown.

Carbon storage and annual sequestration

The role of carbon in climate change is pivotal. This is because the temperature of the Earth depends upon a balance between incoming energy from the sun and that returning back into space. Carbon dioxide (CO_2) absorbs heat that would otherwise be lost to space. Some of this energy is re-emitted back to Earth causing additional warming. Trees are an important repository for carbon, both with respect to the total amount of carbon stored as well as the annual sequestration rate. By absorbing carbon dioxide from the atmosphere trees help to combat a key driver of our changing climate.

The i-Tree Eco surveys of Petersfield shows that there is an over reliance on oak: at 10% of the tree population it holds 43% of the stored carbon. There is a risk in a single species contributing so much.

Future tree planting for carbon storage should focus on species which will attain large stature (> 12 m height) upon maturity. It will also be important to choose species that will be tolerant of predicted climate change. As well as the use of tree species already common in the town, species such as bitternut hickory, false acacia or swamp cypress should be considered, depending on other desirable features, and suitability to the location in question (see Appendix VI).

Habitat Provision

Trees and shrubs provide valuable habitat and food for many animal and plant species, from non-vascular plants, such as moss, to insects, birds and mammals.

Pollinating insects provide ecosystem services by pollinating food crops, but they are under threat from pressures including land-use intensification and climate change[27]. Providing food sources could help. Petersfield's trees and shrubs contribute, with nineteen of the tree species found in the i-Tree survey supporting pollinating insects according to the Royal Horticultural Society 'Perfect for Pollinators plant list'[28] (Table 11).

Many insect herbivores are supported by trees and shrubs. Some specialise on just a few tree species, whilst others are generalists that benefit from multiple tree and shrub species. Of the species found in the Petersfield survey and for which insect data are available[29], willow and oaks support the most varied insect herbivore species.

Table 11. Trees encountered in Petersfield that are beneficial to pollinators[27].

Species	Season
Apple	Spring
Bay laurel	Summer
Blackthorn	Spring
Cherry	Spring
Crab apple	Spring
False acacia (*Robinia*)	Summer
Field maple	Spring
Goat willow	Spring
Hawthorn	Summer
Holly	Spring, Summer
Horse chestnut	Spring
Lime, small-leafed	Summer
Lime, large-leafed	Summer
Norway maple	Spring
Pear	Spring
Plum	Spring
Rowan	Summer
Sycamore	Spring
Whitebeam	Summer

The numbers of insect species supported by tree species encountered in the Petersfield survey are shown in Table 12. Non-native trees tend to associate with fewer insect species than native trees as they have had less time to form associations with native organisms[30]. In addition, some native species form few insect - herbivore associations due to their high level of defence mechanisms, yew being a good example[31]. These species may support wildlife in other ways, for example by supplying structural habitat dead wood[32].

Table 12. Numbers of insect species supported by tree species encountered in the Petersfield survey. Brightest green boxes denote tree species supporting the most insects and red denote the lowest number. Middle values are represented by a gradient between the two.

Species	Total	Beetles	Flies	True bugs	Wasps, sawflies	Moths and butterflies	Other
Willows	450	64	34	56	104	162	9
Oak	423	67	7	81	70	189	9
Birches	334	57	5	30	42	179	9
Hawthorn	209	20	5	40	12	124	8
Poplars	189	32	14	42	29	69	3
Scots pine	172	87	2	25	11	41	6
Blackthorn	153	13	2	25	7	91	11
Common alder	141	16	3	32	21	60	9
Elms	124	15	4	22	6	55	11
Crab apple	118	9	4	12	2	71	2
Hazel	106	18	7	19	8	48	6
Beech	98	34	6	11	2	41	4
Norway spruce	70	11	3	14	10	22	1
Ash	68	1	9	7	7	25	9
Rowan	58	8	3	6	6	33	2
Limes	57	3	5	14	2	25	8
Hornbeam	51	5	3	10	2	28	2
Field maple	51	2	5	10	2	24	6
Sycamore	43	2	3	11	2	20	5
European larch	38	6	1	9	5	16	1
Common juniper	32	2	5	1	1	15	2
Firs	11	8	0	0	0	3	0
Sweet chestnut	11	1	0	1	0	9	0
Holly	10	4	1	2	0	3	0
Horse chestnut	9	0	0	5	0	2	2
English yew	6	0	1	1	0	3	1
Black locust	2	0	0	1	1	0	0

Data from: Southwood (1961) and Kennedy and Southwood (1984)

Risks of Pests and Disease

Pests and diseases are a serious threat to some tree species. Severe outbreaks have occurred within living memory, with Dutch Elm Disease killing approximately 30 million trees in the UK[33]. Climate change may exacerbate this problem, ameliorating the climate for some pests and diseases, making outbreaks more likely[34]. Assessing the risk that pests and diseases pose to urban trees is, therefore, of paramount importance. A risk matrix was devised for determining the potential impact of a pest or disease should it become established in the urban tree population of Petersfield on a single genus (Table) and for multiple genera (Table).

Table 13. Risk matrix used for the probability of a pest or disease becoming prevalent in Petersfield on a single genus (one or more species).

Prevalence	**% Population**		
	0-5	6-10	>10
Not in UK			
Present in UK			
Present in Hampshire			

Table 14. Risk matrix used for the probability of a pest or disease becoming prevalent in Petersfield on multiple genera.

Prevalence	**% Population**		
	0-25	26-50	>50
Not in UK			
Present in UK			
Present in Hampshire			

With increased importation of wood and trees in addition to a climate that is becoming more vulnerable to many pests and diseases, ensuring urban forests are resilient is of paramount importance. Protecting trees against threats can be helped by increasing the diversity of tree species across Petersfield. Threats not yet present in the UK, such as Asian longhorn beetle, pose a threat to many species and could potentially devastate a diverse range of urban trees. UK wide initiatives such as plant health restrictions are designed to combat these threats, but many pests are difficult to detect[35]. In order to protect urban forests from all pests and diseases, vigilance is key. Monitoring urban trees for signs of pests and diseases helps fast responses to eradicate pests before they are a problem and informs research targeted at combating diseases in the long term. Members of the Petersfield community can help in tree surveillance through participation in 'citizen science' programmes such the OPAL tree health survey[36] or Observatree[37]

Table gives an overview of the current and emerging pest and diseases that could affect Petersfield's trees, with a focus on those pests and diseases that lead to the death of the tree or pose a significant human health risk; further details on individual pests and diseases are provided in Appendix V– Tree pests and diseases. The tables present the population of Petersfield's trees at risk from each pest and disease, and indicate the likely impact on canopy coverage and to the overall diversity of Petersfield's urban tree stock should the pest or disease become established. The information contained in the tables can be used to inform programmes to monitor for the presence and spread of a pest or disease, and strategies to manage the risks that they pose.

Healthy trees

Chalara ash dieback – Hynenoscyphus fraxinea – has raised serious concerns about the health of our trees and woodlands. A combination of climate change and the accidental and deliberate introduction of invasive species poses a real threat to many UK trees through increased incidence of pests and diseases. This emphasises the importance of managing the existing tree stock and planting new trees that will increase the resilience and robustness of woodland and greenspaces. Local Authorities should review their tree inventories to identify where these may be under threat now or into the future.

Ensuring a diverse range of species and ages of trees can help increase resilience both to attack by pests and diseases and to the extremes in weather forecast under our changing climate.

Advice is available on suitable species for projected climate change from www.righttrees4cc.org.uk.

Table 15. Risks of principal existing and emerging pests and diseases.

Pest / Pathogen	Main species affected in UK	Prevalence in the UK	Prevalence in Hampshire	Risk of spreading to Petersfield area	Population at risk (%)
Acute oak decline	*Quercus robur, Q. petraea*	SE England and Midlands	Confirmed cases in Hampshire	High – already present in Hampshire	10%
Asian longhorn beetle	Many broadleaf species (see Appendix V)	None (previous outbreaks contained)	None	Medium – climate is suitable	60%
Chalara dieback of ash	*Fraxinus excelsior, F. angustifolia*	Many cases across the UK	Confirmed cases in Hampshire	High - already present	10%
Dothistroma (red band) needle blight	*Pinus nigra ssp. laricio, P. contorta var. latifolia, P. sylvestris*	Throughout the UK	Throughout Hampshire	High – already present	1%
Elm Yellows	*Ulnus*	None	None	Medium	20%
Emerald ash borer	*F. excelsior, F. angustifolia*	None	None	Medium risk (imported wood)	10%
Giant polypore	Primarily *Quercus* spp., *Fagus* spp., *Aesculus* spp., *Sorbus* spp. and *Prunus* spp.	Common in urban areas	Common in urban areas	High – probably already present	15%
Gypsy Moth	Primarily *Quercus* spp., secondarily *Carpinus betulus, F. sylvatica, Castanea sativa, Betula pendula* and *Populus* spp.	London, Aylesbury and Dorset	None	Medium – slow spreading	15%
Oak processionary moth	*Quercus* spp.	Pockets in Southern England	None	Medium, small colonies are containable	10%
Oak wilt	*Quercus* spp.	None	None	Medium	10%
Phytophthora alni	*Alnus* spp.	Riparian ecosystems, particularly in SE England	Present	High – already present in Hampshire	3%
Xylella fastidiosa	*Quercus, Ulmus* spp.	None	None	Medium	30%

4. Discussion and Conclusions

i-Tree Eco has provided the means to examine the trees in Petersfield in a comprehensive manner, perhaps for the first time in the modern era. Its results and findings complement other existing databases of Petersfield's trees held by EHDC and HCC, and policy documents such as 'Petersfield Nature. A Biodiversity Action Plan for Petersfield'[38] (2013) and Petersfield's Neighbourhood Plan[39] (2015). The survey has also allowed Petersfield's trees to be put in the spotlight so that serious questions can be asked about their place in the town today and in the future, what they do and don't do for townsfolk, and how the town and its inhabitants might work together to maintain and enhance the tree population. Like many other British towns, cities and other urban centres, Petersfield is subject to a number of pressures to develop and change from its current structure and make up, and these pressures also impact on existing tree populations. In addition, climate change and the potential threat to tree health of invasive insect pests and microbial diseases are increasingly having a bearing on the nature of urban trees and their ability to continue to deliver the range of goods and services that they do today. It is expedient and timely to perform a stocktake, not just of the trees themselves, but of what they deliver for us.

Similarly, whilst the results of the i-Tree Eco survey can be expressed numerically, for example in terms of numbers of trees and species and their calculated financial value to the community, they can be also interpreted as reflecting individual and communal choices regarding preferences for trees. It is important that these are better understood, so that tree management by public agencies can be tuned to echo these needs.

The headline figures for Petersfield's tree cover are in line with the average of values recently determined for a large number of English towns and cities[1]. The average canopy cover across the full sample area of the Petersfield survey is reduced because there is a significant proportion of countryside within the parish boundary and this is dominated by agricultural fields and grassland with very little woodland. This land-use contains a tree cover of 12.9% compared to the built up area of 17.9%. Historically, most of the streets in Petersfield's Conservation Area, the oldest part of the town, contained very few trees – many, for example Sheep Street and Chapel Street, are too narrow for street trees, whilst others such as Dragon Street, High Street and the Square probably never had them[40]. The survey of street trees in the

Conservation area identified a total of only 177 in 2016, an average of one tree every 30 metres of road, or one every 60 metres of pavement. This density is inadequate to provide shade for pedestrians visiting the town centre. Similarly, the average density across the parish area is lower than the 20% canopy cover suggested as a target for inland towns and cities. More concerted tree planting, coupled with measures to protect existing trees, seem to be necessary if Petersfield residents are to continue to enjoy the benefits that trees bring to the town.

The number of tree species identified in both Conservation Area and parish-wide surveys is comparatively large. Native species dominate the make-up of both built up and surrounding countryside elements of the parish, though non-native species are also present, especially in private garden hedges (e.g. Leyland cypress). Non-native ornamental tree species outnumber native ones in the street trees in the Conservation area, though this reflects the need for the amenity that they provide. The large diversity in tree species in Petersfield is to be welcomed as diversity is a major element in building resilient tree populations against hazards such as climate change. In general, there is a reasonable mixture of species across the parish, though the relative importance of ash and elm is of some concern given the vulnerability of these species to mortal diseases (see p. 63 onwards). In addition, some important species for Petersfield (such as alder, ash, cherry and birch) are relatively intolerant of drought. This is likely to be increasingly experienced in the next decades as a result of global warming and could cause vulnerable species to suffer, especially if there are successive droughty years. It will be increasingly necessary to select tree species that are recognised for their drought tolerance, and Appendix VI lists some of these, native and non-native.

The diversity of tree species is also beneficial for the wildlife in Petersfield. Both native and non-native species help support wildlife, though the popularity of Leyland and Lawson cypresses for forming hedging and screening could be challenged – the biodiversity that these species promote is probably quite low[41]. In addition, it is well known that these species can present nuisance problems as they grow taller, and are comparatively costly to maintain. Future tree policies should seek to encourage other forms of hedging, especially those not composed solely of conifer species. The Royal Horticultural Society's webpages give further advice on this subject[42].

The tree stock in Petersfield is dominated by trees of small girth and height, and less than 10% could be described as of large size (> 60 cm diameter at breast height). Nevertheless, most of the species chosen for both private and public use are capable of growing to statures greater than 12 m in height. For example, in the Conservation Area, over 40% of street trees are currently below this height, though 95% are capable of growing to it. This can be interpreted positively as an indication of a progressive tree policy with introduction (or reintroduction) of trees in public areas over several decades. However, the survey also demonstrates that it will be several decades before these trees can provide services such as shade and cooling to the fullness of their ability. It will be important to continue to maintain and manage these trees in order that they grow to large stature, whilst at the same time maintaining those that have done so. Indeed, for a few tree species, there is already some cause for concern over their general condition, especially within the built up area.

The density of urban trees in Petersfield is quite variable from place to place – some districts are much more silvan than others. Major influences on tree density are (a) the location of the Tilmore Brook and its tributaries, (b) the routes of the disused Petersfield to Midhurst railway line, and (c) the mainline from London to Portsmouth, especially south-west of the railway station. Other concentrations of trees occur on the Heath, and in field boundaries to the south and west of the Chichester Road (B2146) and on Penns Farm. The Bedford Road industrial area to the east of the A3 also supports perhaps a surprising number of trees, many planted to screen the larger manufacturing units built in the late 1970s[43]. Petersfield Central Car Park benefits from the presence of a reasonable tree cover, but the trees at the Tesco car park are younger and much less prominent, whilst almost totally absent from the two railway and other town centre car parks. As a general rule, dwellings with large gardens have more room and therefore larger numbers of trees than smaller ones. Provision of street trees in housing areas is seemingly dependent on location and the phase of development when houses were built. So, for example, there is a reasonable density in parts of the Herne Farm estate, especially to the south of Tilmore Brook, and in the development encircled by College Street and Tor Way. In contrast, other areas, notably to the west of the town, have very few street trees.

The i-Tree surveyors were asked to assess the extent to which land in the 200+ plots were capable of bearing more trees. They considered that almost 70% of the surrounding countryside and a quarter of the built up area could be planted with additional trees should this be judged desirable on other grounds. Of course, much of the countryside is already supporting agriculture and there are other significant constraints on further tree establishment, not least inertia and resistance to change. Nevertheless, the survey provides a strong indication that the tree population of Petersfield could be increased significantly if there was a will to do so.

The need for additional trees should be considered in the context of the need for the goods and services they provide, now and especially in the future. But as well as planning to optimise the contributions that existing and new trees might make to the town and its community, it is also important to recognise various forces that act to reduce tree numbers. For example, climate change is predicted to seriously challenge the health and even survival of some tree species in the town, whilst diseases such as ash die-back will inevitably reduce tree numbers over time. Coupled to this is the modern movement, in Petersfield and elsewhere, to improve home liveability by building extensions, conservatories, garages, security fences and off-road parking facilities – established trees are often a casualty of such developments. Tree security is threatened by larger developments and highway redesign. Many trees are exposed to the ill-effects of grass mowing, and sadly still to vandalism. And finally, of course, trees not overcome by the damaging agencies listed above will inevitably succumb to old age. For some species, such as cherry, birch, alder and rowan, lifespan can be quite short.

The i-Tree Eco survey has formally identified the wide range of ecological goods and services that Petersfield's tree provide to its inhabitants and those who visit for work or recreation. In addition, it has placed monetary values of some of the most important ones, and also estimated the total asset value of the tree population. The i-Tree and CAVAT methodologies have received considerable professional and scientific scrutiny, and have been accepted as providing credible information by several UK government agencies[44].

Some of the monetary values for the services provided by Petersfield's tree population are very large. They will probably surprise many people. An estimated replacement cost of £50.7 million, and an amenity value of just under £498 million reveals just how important the current tree population is. To these figures can be added a carbon storage value of nearly £4.2 million and other significant amounts for £9.5 million, £425,000 and £498,000 as asset values for lifetime (50 year) delivery of carbon sequestration, avoided runoff (flood prevention) and air pollution absorption respectively. These figures actually underestimate the value of Petersfield's trees because other important services such as wildlife habitat, noise absorption and urban cooling haven't been monetised. And it is not possible using an extensive survey approach, to explore the value of Petersfield trees for attracting visitors and shoppers, for supporting health and instilling well-being or for enhancing property values. The value of these additional 'services' could be very large too.

The benefits that the Petersfield tree 'asset' confers on the town and its community are dependent upon the public, private industry and residential sectors to maintain and enhance it. Considered alongside other town assets such as infrastructure, equipment and networks, there is an urgent need to formalise policies to protect and manage it. Except in Petersfield's Conservation Area, or where trees are identified with Tree Preservation Orders, householders have the freedom to plant, and remove, trees from their property without seeking approval or permission. Thus for the private and residential sectors, local authorities should encourage tree planting and maintenance through the communication and promotion of a tree strategy for the town or district. This should clearly demonstrate the advantages that trees offer the community and should define a tree policy which strongly supports the retention of trees and their ability to grow to maturity. Such a policy should be co-produced with the community so that a shared responsibility for tree care is sought. It should include advice on species selection to guide home owners and other private land holders who wish to contribute to increasing Petersfield's tree cover. Information in and behind this report should be used creatively to enthuse and excite – it has a bearing not only on policies for green infrastructure but for housing, transport and tourism. Similarly, the public sector should identify budgets for capital and renewal programme expenditure for maintenance and replacement commensurate with the size of the public tree asset, in accordance with HM Treasury instruction[45].

Seeking to 'retrofit' trees into streets and other areas of hard infrastructure is unlikely to be possible in many parts of Petersfield, though fallen or felled trees should always be replaced with new ones. Instead, consideration should be given to tree planting in areas currently laid out to grass, for example large grass verges, traffic islands and roundabouts, small parks and around playing fields. In addition, opportunities for the introduction of suitable trees should always be explored when redevelopment or new development is scheduled. In these cases, the minimum target for the number of trees should be such that it exceeds current tree densities in the town – to do otherwise is to, perhaps unwittingly, support a policy of tree number reduction. Tree proposals should be bold and exciting, and reflect the opportunities for delivery of a wide range of ecosystem benefits. However, it is vital that plans for trees are also examined for any unwanted 'disbenefits' such as honeydew nuisance, and adjusted if necessary. They should also be tested for their resilience in the face of known hazards such as climate change and the indirect consequences of it. All planting schemes should adhere to the 'Right Tree for the Right Place' maxim, and ensure that tree species are matched to the site conditions (e.g. soil, microclimate, drainage regime) at the chosen site and that the characteristics at maturity (height, canopy width, etc.) are appropriate for the locality and specific site in question.

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Appendix I - Detailed Methodology

Field measurements and i-Tree Eco Models

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

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

Field data were collected during the growing season to allow accurate tree canopy assessment and to facilitate tree species identification. For each plot, data collected included land use (Table A1), ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, canopy missing and dieback, as required by the i-Tree Eco method. The full method can be viewed in the i-Tree Eco User's Manual www.itreetools.org/resources/manuals.php.

Calculating the volume of stormwater intercepted by woody vegetation: during precipitation events, a portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff. In urban areas, large extents of impervious surfaces can lead to highs amounts of surface runoff and to [localised] flooding during periods of high rainfall.

Table A1. Land use definitions (adapted from the i-Tree Eco v6 manual).

Land-use	Definition
Residential	Freestanding structures serving one to four families each. Detached, semi-detached houses, bungalows, terraced housing.
Multi-family residential	Structures containing more than four residential units. Flats, apartment blocks.
Commercial / Industrial	Standard commercial and industrial land uses, including outdoor storage/staging areas, car parks not connected with an institutional or residential use. (Retail, manufacturing, business premises).
Park	Parks, includes unmaintained as well as maintained areas. (Recreational open space, formal and informal).
Cemetery	Includes any area used predominantly for interring and/or cremating, including unmaintained areas within cemetery grounds.
Golf Course / Playing fields	Used predominately for sport.
Agriculture	Cropland, pasture, orchards, vineyards, nurseries, farmsteads and related buildings, feed lots, rangeland, woodland. Plantations for a specific crop or tree production are included.
Vacant	Derelict, brownfield or current development site. Includes land with no clear intended use. Abandoned buildings and vacant structures should be classified based on their original intended use.
Institutional	Schools, hospitals/medical complexes, colleges, religious buildings, government buildings.
Utility	Power-generating facilities, sewage treatment facilities, covered and uncovered reservoirs, and empty stormwater runoff retention areas, flood control channels, conduits.
Water/wetland	Streams, rivers, lakes, and other water bodies (natural or man-made). Small pools and fountains are classified based on the adjacent land use.
Transportation	Includes limited access roadways and related greenspaces; railway stations, tracks and yards. If plot falls on other type of road, classify according to nearest adjacent land use.
Other	Land uses that do not fall into one of the categories listed above. This designation should be used very sparingly as it provides very little useful information for the model.

[NOTE: For mixed-use, land use is based on the dominant use, i.e. the use that receives the majority of the foot traffic whether or not it occupies the majority of space.]

i-Tree Eco calculates the volume of precipitation intercepted by trees in order to enable valuation based upon, for example, flood alleviation or cost of treating surface water runoff avoided. To calculate the volume of surface runoff avoided, the i-Tree model considers both precipitation interception by vegetation and runoff from pervious and impervious surfaces. This requires information collected during the field survey.

To calculate the volume of precipitation intercepted by vegetation, i-Tree Eco assumes an even rainfall distribution. The model considers the volume of water intercepted by vegetation, the volume of water dripping from the saturated canopy minus water evaporation from the canopy during the rainfall event, and the volume of water evaporated from the canopy after the rainfall event. The same process is applied to water reaching impervious ground, with saturation of the ground causing surface runoff. Pervious cover is treated similarly, but with a larger storage capacity over time. The volume of avoided runoff is then calculated. The model[46] is relatively simple and factors such as the effect tree roots have on soil drainage are not included.

The cost of treating surface water runoff avoided is not reported directly by most water treatment companies. For i-Tree Eco studies conducted in Wales, it could be inferred as the standard volumetric rate per cubic metre charge (i.e. the cost of removing, treating and disposing of used water including a charge for surface water and highway drainage) minus the standard volumetric rate–surface water rebated per cubic metre charge (i.e. the cost of removing, treating and disposing of used water). Using 2015/16 prices set by Welsh Water, this calculates as £1.6763 - £1.3238 = £0.35 per m^3 (i.e. the cost of managing surface water, or the surface water rebate charge).

However, this 'avoided charges' cost is a conservative estimate of the total 'avoided charges' across the full survey area as it does not account for infrastructural, operational and treatment charges linked to surface water management by, for example, Local Authorities, Internal Drainage Boards and Natural Resources Wales. Therefore, the Standard volumetric rate – Surface water rebated per cubic metre value of £1.3238 was used as a representative value of the avoided cost of treating surface water runoff across the whole survey area in i-Tree Eco studies conducted in Wales in 2014/15. For a similar study in Edinburgh, a value of £1.3464 was used[47], based on charges levied by Scottish Water[48]. Consequently, a Volumetric Waste Water Charge of £1.3464 is used in this Petersfield i-Tree Eco study as likely to be representative of circumstances in the town.

Calculating current carbon storage: biomass for each tree was calculated using allometric equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[49]. 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*.

Calculating 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[50]. 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[51] that were adjusted depending on leaf phenology and leaf area. Particulate removal assumes a 50% re-suspension rate of particles[52].

Replacement costs: are based on valuation procedures of the US Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information[53], calculated using standard i-Tree inputs such as per cent canopy missing.

Tree condition: trees are assigned to one of seven classes according to percentage dieback in the crown area:

- excellent (less than 1% dieback)
- good (1% to 10% dieback)
- fair (11% to 25% dieback)
- poor (26% to 50% dieback)
- critical (51% to 75% dieback)
- dying (76% to 99% dieback)
- dead (100% dieback).

This dieback does not include normal, natural branch dieback, i.e. self-pruning due to crown competition or shading in the lower portion of the crown. However, branch dieback on side(s) and top of crown area due to shading from a building or another tree would be included.

Monetising carbon and pollutant capture

In the UK, the most appropriate way to monetise carbon sequestration benefit is to multiply the tonnes of carbon stored (from i-Tree calculations) by the non-traded price of carbon (i.e. carbon that is not part of the EU carbon trading scheme). The non-traded price is based on the industrial cost of not emitting the tonne of carbon in order to remain compliant with the Climate Change Act (2008). The unit values used were based on those given by the Department of Energy & Climate Change (DECC)[54].

Official pollution values for the UK are based on the estimated social cost of the pollutant based on its impact upon human health, damage to buildings and crops. This approach is termed 'the costs approach'. Values were taken from Defra's Interdepartmental Group on Costs and Benefits (IGCB)[55].

There are three levels of 'sensitivity' applied to the air pollution damage cost approach: 'High', 'Central' and 'Low'. This report uses the 'Central' scenario based on 2015 prices.

The damage costs exclude several key effects because their quantification and valuation is not possible or is highly uncertain. These are:

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

CAVAT Analysis

Previous i-Tree Eco studies conducted in the UK have employed an adjusted version of the CAVAT Full-method in their CAVAT valuations. However, the amenity value of trees for the two Petersfield surveys was assessed according to the CAVAT Quick method following the recommendation of the CAVAT steering group. To reach a CAVAT Quick method valuation, the following steps were completed:

- Basic Value Calculation. Basal Stem Area, calculated from DBH, multiplied by the unit value factor. The unit value factor, which is also used in CTLA analysis, is the cost of replacing trees, presented in £ per cm^2 of trunk diameter. The Unit value factor can be obtained from the London Tree Officers Association (LTOA) webpages (http://www.ltoa.org.uk/resources/cavat).

- Community Tree Index rating (CTI) calculation. The CTI rating reflects local population density, and in this study it was kept constant across the Petersfield area at 100%. This means that in reality, the CAVAT analysis focused on accessibility, functionality, appropriateness and SLE. Guidance on which CTI value to use is available at http://www.ltoa.org.uk/documents/doc_download/125-national-community-tree-index.

- Crown size calculation. Crown size is calculated from the Canopy Missing (%) variable in the survey results. The crown size is rounded down to the nearest 20% (i.e. 0%, 20%, 40%, 60%, 80%, 100%).

- Crown condition calculation. Crown condition is calculated from the Crown Dieback (%) variable in the survey results. The crown condition is rounded down to the nearest 20% (i.e. 0%, 20%, 40%, 60%, 80%, 100%).

- Life expectancy calculation. The life expectancy factor declines exponentially based on number of years of safe life expectancy (SLE) left (see Table A2). However, this step was completed using 20-40 years as a figure applicable across Petersfield.

Table A2. Life expectancy conversion factors.

SLE (years)	Factor
80+	100%
40-80	95%
20-40	80%
10-20	55%
5-10	30%
<5	10%
Tree is dead	0%

The CAVAT value was then calculated by multiplying all the steps:

Basic Value x CTI x Crown size x Crown condition x Life expectancy

Appendix II - Species Importance List – Petersfield Parish survey

Table A3 gives Importance Values for all species encountered during the Petersfield parish survey. Absence of a tree species doesn't mean that it is missing from Petersfield's tree population, but that it wasn't identified in the sample plots surveyed in 2016.

Table A3. Importance values, Per cent leaf areas and proportion of total Petersfield tree population for 69 tree species identified during the i-Tree Eco survey.

Rank	Species	Importance Value	Percent Leaf Area	Percent Population
1	Oak (*Q. robur/petraea*)	31.4	21.6	9.9
2	Elm	30.0	10.1	19.9
3	Common ash	18.8	8.4	10.4
4	Hazel	18.5	10.1	8.4
5	Field maple	10.1	5.4	4.7
6	Beech	7.2	6.1	1.2
7	Holly	6.5	2.0	4.4
8	Leyland cypress	5.6	0.8	4.8
9	Horse chestnut	5.6	5.1	0.4
10	Hawthorn	5.3	1.0	4.4
11	Common alder	5.1	2.5	2.6
12	Silver birch	4.6	2.1	2.5
13	Small leaved lime	4.4	4.1	0.3
14	Cypress (non specified)	4.3	1.7	2.7
15	Sycamore	3.9	2.1	1.8
16	Douglas fir	3.5	2.5	1.0
17	Cherry (non specified)	3.4	0.9	2.4
18	Apple	2.3	0.9	1.4
19	Scots pine	2.3	1.1	1.2
20	Norway spruce	2.2	1.5	0.7
21	Common yew	2.0	0.7	1.3
22	Willow (non specified)	2.0	1.2	0.7
23	Poplar (non specified)	1.4	0.4	1.0
24	Black locust	1.4	0.7	0.6
25	Rowan	1.4	0.3	1.1
26	Common lime	1.2	0.4	0.7
27	Maple (non specified)	0.9	0.4	0.5
28	Elder	0.9	0.1	0.7
29	Large-leaved lime	0.9	0.7	0.2
30	Goat willow	0.8	0.3	0.5
31	Western red cedar	0.8	0.6	0.1
32	Cedar species	0.8	0.4	0.4
33	Siberian larch	0.7	0.6	0.1
34	Norway maple	0.7	0.2	0.5
35	Lilac (non specified)	0.6	0.1	0.5
36	Monterey cypress	0.5	0.2	0.3
37	Turkey oak	0.5	0.3	0.2
38	Magnolia (non specified)	0.5	0.2	0.3

Rank	Species	Importance Value	Percent Leaf Area	Percent Population
39	Pear	0.5	0.2	0.3
40	Portugal laurel	0.4	0.1	0.3
41	Cider gum	0.4	0.3	0.1
42	Smoke tree	0.4	0.0	0.3
43	Blackthorn	0.4	0.0	0.3
44	Lawson cypress	0.3	0.0	0.3
45	Aspen	0.3	0.2	0.1
46	Swedish Birch	0.3	0.1	0.2
47	Common laburnum	0.3	0.2	0.1
48	Japanese cherry	0.2	<0.1	0.2
49	Downy birch	0.2	0.1	0.1
50	Italian alder	0.2	<0.1	0.2
51	Cotoneaster	0.2	0.1	0.1
52	Hornbeam	0.2	0.1	0.1
53	Western hemlock	0.2	0.1	0.1
54	Northern white cedar	0.2	0.1	0.1
55	Green ash	0.2	<0.1	0.1
56	Liquidambar	0.2	<0.1	0.2
57	Broom	0.1	<0.1	0.1
58	Sumac	0.1	<0.1	0.1
59	Plum	0.1	<0.1	0.1
60	Juniper	0.1	<0.1	0.1
61	Hinoki Cypress	0.1	<0.1	0.1
62	Yucca	0.1	<0.1	0.1
63	Italian cypress	0.1	<0.1	0.1
64	Chinese willow	0.1	<0.1	0.1
65	Larch (non specified)	0.1	<0.1	0.1
66	Laurel	0.1	<0.1	0.1
67	Crab apple	0.1	<0.1	0.1
68	Cordyline	0.1	<0.1	0.1
69	Gleditsia	0.1	<0.1	0.1

Appendix III - Species Importance List – Petersfield Conservation Area

Importance values for all tree species encountered during the survey of public trees in Petersfield Conservation Area.

Rank	Species	Importance Value	Percent Leaf Area	Percent Population
1	Common ash	24.6	11.1	13.6
2	Common lime	22.2	13.7	8.5
3	London plane	12.6	8.6	4.0
4	Silver lime	10.9	3.0	7.9
5	English oak	9.8	4.7	5.1
6	Western red cedar	9.1	6.3	2.8
7	Norway maple	8.5	5.1	3.4
8	Common yew	7.9	5.6	2.3
9	Sycamore	7.1	2.0	5.1
10	Horse chestnut	6.7	4.5	2.3
11	Chanticleer pear	6.5	1.9	7.3
12	Myrobalan plum	6.2	1.7	4.5
13	Rowan	5.7	1.7	4.0
14	Hornbeam	5.1	3.4	1.7
15	Dawn redwood	5.1	4.0	1.1
16	Silver maple	4.6	2.9	1.7
17	Whitebeam	4.6	2.3	2.3
18	Common beech	4.4	0.4	4.0
19	Field maple	3.8	2.1	1.7
20	Holly oak	3.3	2.7	0.6
21	Caucasian 'Raywood' ash	3.2	1.5	1.7
22	Giant sequoia	3.1	2.5	0.6
23	Black locust	2.3	0.6	1.7
24	Turkish hazel	2.2	0.5	1.7
25	Silver birch	2.2	0.5	1.7
26	Deodar cedar	2.2	1.6	0.6
27	Italian alder	2.1	0.4	1.7
28	Copper beech	2.1	0.9	1.1
29	Hawthorn	1.8	0.1	1.7
30	Purple crab apple	1.6	1.0	0.6
31	Red horse chestnut	1.3	0.7	0.6
32	Wild cherry or Gean	0.9	0.4	0.6
33	Himalayan tree-Cotoneaster	0.8	0.2	0.6
34	Common alder	0.7	0.1	0.6
35	Japanese rowan	0.7	0.1	0.6
36	Common box	0.6	<0.1	0.6

Appendix IV. Non-traded values for carbon stored in Petersfield's trees

These values are based on the UK government's non-traded carbon valuation method and assume the structure of the urban forest remains the same over time.

Year	Stored C (t)	Net sequestered C (t)	Stored C (tCO_2e)	Net sequestered C (tCO_2e)	Non-traded unit value (£/tCO_2e)	Discount rate	Discount factor	Value of discounted stored tCO_2e (£)
2015	18,261	580	66,957	2,126	£62	3.5	1.00	4,151,334
2016	18,841	580	69,083	2,126	£63	3.5	0.97	4,199,919
2017	19,421	580	71,210	2,126	£64	3.5	0.93	4,243,978
2018	20,001	580	73,336	2,126	£65	3.5	0.90	4,283,630
2019	20,581	580	75,462	2,126	£66	3.5	0.87	4,318,995
2020	21,161	580	77,589	2,126	£67	3.5	0.84	4,350,195
2021	21,740	580	79,715	2,126	£68	3.5	0.81	4,377,355
2022	22,320	580	81,841	2,126	£69	3.5	0.78	4,400,598
2023	22,900	580	83,967	2,126	£71	3.5	0.75	4,483,194
2024	23,480	580	86,094	2,126	£72	3.5	0.73	4,498,313
2025	24,060	580	88,220	2,126	£73	3.5	0.70	4,509,860
2026	24,640	580	90,346	2,126	£74	3.5	0.68	4,517,962
2027	25,220	580	92,473	2,126	£75	3.5	0.65	4,522,745
2028	25,800	580	94,599	2,126	£76	3.5	0.63	4,524,335
2029	26,380	580	96,725	2,126	£77	3.5	0.61	4,522,856
2030	26,960	580	98,852	2,126	£78	3.5	0.59	4,518,430
2031	27,539	580	100,978	2,126	£86	3.5	0.57	4,910,903
2032	28,119	580	103,104	2,126	£93	3.5	0.55	5,232,668
2033	28,699	580	105,230	2,126	£100	3.5	0.53	5,541,570
2034	29,279	580	107,357	2,126	£108	3.5	0.51	5,892,124
2035	29,859	580	109,483	2,126	£115	3.5	0.49	6,174,344
2036	30,439	580	111,609	2,126	£122	3.5	0.47	6,443,677
2037	31,019	580	113,736	2,126	£129	3.5	0.46	6,700,189
2038	31,599	580	115,862	2,126	£137	3.5	0.44	6,995,027
2039	32,179	580	117,988	2,126	£144	3.5	0.43	7,225,312

Year	Stored C (t)	Net sequestered C (t)	Stored C (tCO_2e)	Net sequestered C (tCO_2e)	Non-traded unit value (£/tCO_2e)	Discount rate	Discount factor	Value of discounted stored tCO_2e (£)
2040	32,759	580	120,115	2,126	£151	3.5	0.41	7,443,123
2041	33,338	580	122,241	2,126	£159	3.5	0.40	7,697,035
2042	33,918	580	124,367	2,126	£166	3.5	0.38	7,889,529
2043	34,498	580	126,493	2,126	£173	3.5	0.37	8,070,097
2044	35,078	580	128,620	2,126	£180	3.5	0.36	8,281,643
2045	35,658	580	130,746	2,126	£188	3.5	0.35	8,528,929
2046	36,238	580	132,872	2,126	£195	3.0	0.34	8,720,654
2047	36,818	580	134,999	2,126	£202	3.0	0.33	8,902,917
2048	37,398	580	137,125	2,126	£210	3.0	0.32	9,119,249
2049	37,978	580	139,251	2,126	£217	3.0	0.31	9,282,263
2050	38,558	580	141,378	2,126	£224	3.0	0.30	9,436,159
2051	39,137	580	143,504	2,126	£232	3.0	0.29	9,622,547
2052	39,717	580	145,630	2,126	£240	3.0	0.28	9,798,797
2053	40,297	580	147,756	2,126	£247	3.0	0.27	9,924,882
2054	40,877	580	149,883	2,126	£255	3.0	0.26	10,081,973
2055	41,457	580	152,009	2,126	£263	3.0	0.26	10,229,411
2056	42,037	580	154,135	2,126	£270	3.0	0.25	10,329,117
2057	42,617	580	156,262	2,126	£277	3.0	0.24	10,420,801
2058	43,197	580	158,388	2,126	£284	3.0	0.23	10,504,639
2059	43,777	580	160,514	2,126	£291	3.0	0.23	10,580,811
2060	44,357	580	162,641	2,126	£298	3.0	0.22	10,649,500
2061	44,936	580	164,767	2,126	£304	3.0	0.21	10,675,772
2062	45,516	580	166,893	2,126	£309	3.0	0.21	10,661,654
2063	46,096	580	169,019	2,126	£314	3.0	0.20	10,643,039
2064	46,676	580	171,146	2,126	£318	3.0	0.19	10,586,790
2065	47,256	580	173,272	2,126	£322	3.0	0.19	10,527,547

Appendix V – Pests and Diseases

This section includes summaries of the principal insect pests and microbial pathogens that could affect the health of commonly occurring trees in Petersfield. It also identifies *emerging* risks posed by pests and pathogens that could arrive in Britain over the next few years. The material in this section can be used to assess the vulnerability of existing trees to pests and diseases, as well as help in the choice of trees to form new plantings.

Existing pests and diseases

Acute Oak Decline

Acute oak decline (AOD) affects mature oak trees (>50 years old) of both native oak species (common oak and sessile oak). Over the past four years, the reported incidents of stem bleeding, a potential symptom of AOD, have been increasing. The condition seems to be most prevalent in the Midlands and the South East of England as far west as Wales. The incidence of AOD in Britain is unknown but estimates put the figure at a few thousand affected trees. The Petersfield area appears at risk from the disease.

Chalara Dieback of Ash

Ash dieback, caused by the fungus *Hynenoscyphus fraxineus*, targets common and narrow leaved ash. Young trees are particularly vulnerable and can be killed within one growing season of symptoms becoming visible. Older trees take longer to succumb, but can die from the infection after several seasons. *H. fraxinea* was first recorded in the UK in 2012 in Buckinghamshire and has now been reported across the UK, including in urban areas. There is some evidence from continental Europe that urban trees are less susceptible to attack than their rural counterparts[56]. Nevertheless, ash dieback poses a serious threat to about 10% of Petersfield's trees.

Dothistroma needle blight

Dothistroma (red band) needle blight is the most significant disease of coniferous trees across the UK. The disease causes premature needle defoliation, and, in severe cases, tree death. It is now found in many forests growing susceptible pine species, with Corsican, lodgepole and, more recently, Scots pine all being affected. While there are no reported cases of red band needle blight on urban trees, 1% of Edinburgh's tree population is potentially at threat from it.

Giant Polypore

Giant polypore (*Meripilus giganteus)* is a fungus that can cause internal decay in trees without any external symptoms, causing trees to potentially topple or collapse. It is particularly common in urban areas and can also cause defoliation and crown dieback[57]. Giant polypore predominantly affects hardwoods such as horse chestnut, beech, cherry, lime, mountain ash and oak. Approximately 15% of Petersfield's trees could be vulnerable to giant polypore.

Phytophthora diseases of alder

Phytophthora alni affects all alder species in Britain and was first discovered in the country in 1993. *Phytophthora siskiyouensis* has recently been identified as affecting grey alder (*Alnus incana*). Phytophthora diseases of alder are now widespread in the riparian ecosystems in the UK where alder commonly grows. On average, the disease incidence is highest in southeast England. *Phytophthora* disease poses a threat to about 3% of Petersfield's trees.

Potential pests and diseases

Asian Longhorn Beetle

Asian Longhorn Beetle (ALB) is a major pest in China, Japan and Korea, where it kills many broadleaved species. In America, ALB has established populations in Chicago and New York. Where the damage to street trees is severe, felling, sanitation and quarantine are the only viable management options.

In March 2012, an ALB outbreak was found in Maidstone, Kent. More than 2,000 trees were removed from the area to contain the outbreak. A second outbreak has also been reported in the UK and contained.

Models of climatic suitability for ALB based on data from China and the USA[58] suggest that CLIMEX Ecoclimatic Indices of >32 identify suitable habitats for ALB (Figure A1). This indicates that Petersfield is vulnerable to ALB under this model. If an ALB outbreak did occur in Petersfield, it would pose a significant threat to about 60% of the trees, not including attacks on shrub species.

Known host tree species include: *Acer* spp. (maples and sycamores), *Aesculus* spp. (horse chestnut), *Alnus* spp. (alder), *Betula* spp. (birch), *Carpinus* spp. (hornbeam), *Corylus* spp. (hazel), *Fagus* spp. (beech), *Fraxinus* spp. (ash), *Populus* spp. (poplar), *Prunus* spp. (cherry, plum), *Robinia pseudoacacia* (false acacia/black locust), *Salix* spp. (willow, sallow) *Sorbus* spp. (mountain ash/rowan, whitebeam etc) and *Ulmus* spp. (elm).

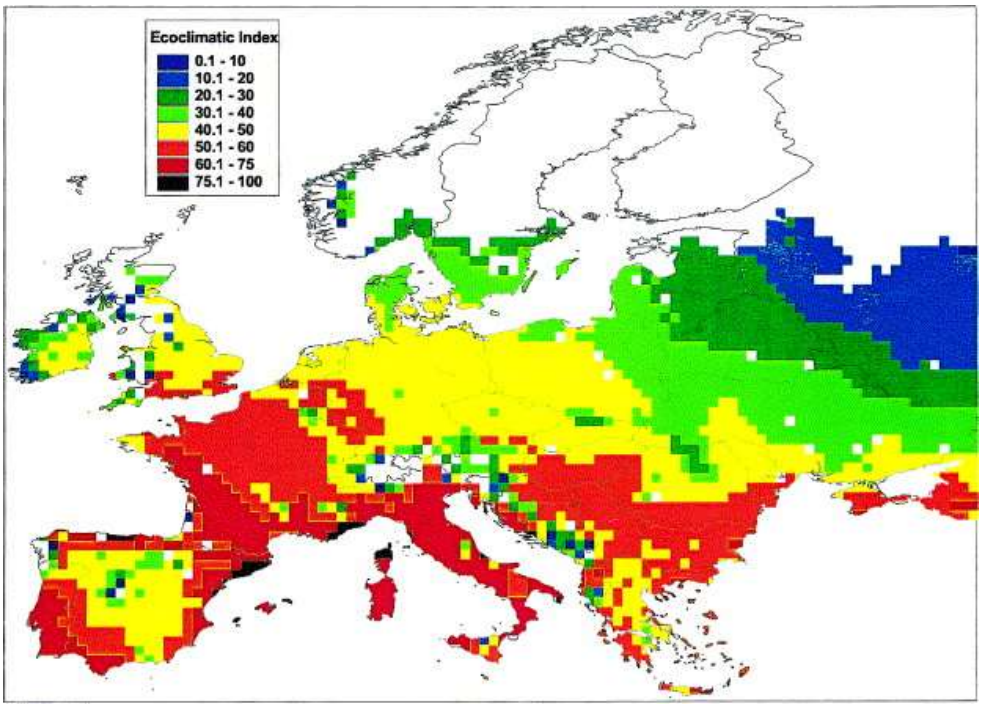

Figure A1. CLIMEX Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB (Ref: MacLeod *et al.,* 2002).

Elm yellows

Elm yellows is a disease of elm trees caused by a bacterium-like microbe. The disease is not yet present in the UK although we had an outbreak in 2014. The disease causes a range of symptoms that could include yellowing, dwarfing and premature shedding of leaves, formation of 'witches' brooms' at the tips of twigs and branches, early opening of buds, and in some occasions reddish colouration of the foliage. In very susceptible elms, the inner bark of the tree is attacked, effectively girdling and stopping the flow of water and nutrients. Symptoms can easily be confused for symptoms of Dutch elm disease (DED). However, trees affected by DED will die back and die rapidly, whereas Elm Yellows can be expected to cause symptoms which do not result in the death of the tree.

Elm yellows can affect healthy elm trees that are resistant DED. Up to 20% of Petersfield's tree population is therefore at risk from Elm yellows if it arrives in Britain permanently.

Emerald Ash Borer

There is no evidence to date that the insect known as the emerald ash borer (EAB) is present in the UK, but the increase in global movement of imported wood and wood packaging poses a significant risk of its accidental introduction. EAB is present in Russia and is moving west and south at a rate of 30-40 km per year[59]. EAB has had a devastating effect in the USA due to its accidental introduction and could add to pressures already imposed on ash trees from diseases such as Chalara dieback of ash. Emerald Ash Borer poses a potential future threat to about 10% of Petersfield's trees.

Gypsy Moth

Gypsy moth is an important defoliator of a very wide range of trees and shrubs in mainland Europe, where it periodically reaches outbreak numbers. It can cause tree death if successive, serious defoliation occurs on a single tree. A small colony has persisted in northeast London since 1995 and a second breeding colony was found in Aylesbury, Buckinghamshire in the summer of 2005. Some suggest that the climate in the UK is suitable for Gypsy Moth should it arrive here and that it would become more so as global temperatures rise. However, the spread of gypsy moth in the USA has been slow, invading less than a third of its potential range[60]. If Gypsy Moth spread to Petersfield, it would pose a threat to about 15% of its trees.

Oak Processionary Moth

Established breeding populations of oak processionary moth (OPM) have been found in South and South West London, in Berkshire and now beyond. It is thought that OPM has been spread on nursery trees. The outbreak in London is now beyond eradication, and while efforts to contain the spread out beyond Berkshire are underway, new cases were reported in 2015 in Guildford, Surrey. The caterpillars cause serious defoliation of oak trees, their principal host, but the trees will recover and leaf the following year. On the continent, they have also been associated with hornbeam, hazel, beech, sweet chestnut and birch, but usually only where there is heavy infestation of nearby oak trees. The caterpillars have irritating hairs that carry a toxin that can be blown in the wind and cause serious irritation to the skin, eyes and bronchial tubes of humans and animals. They are considered a significant human health problem when populations reach outbreak proportions, such as those in The Netherlands and Belgium have done in recent years. Oak processionary moth poses a threat to nearly 10% of Petersfield's trees.

Oak Wilt

This is caused by the fungus *Ceratocystis fagacearum* and is currently only known to be present in the USA where it has resulted in the death of many thousands of native oak trees. However, European oak species are susceptible and can be killed by the disease. In urban areas where susceptible oaks are abundant, the impact on property or other social values has been significant. In central Texas, for instance, oak wilt has caused considerable decline in urban and rural property values through landscape degradation, shade loss and a resulting decline in property values.

Xylella fastidiosa

Xylella fastidiosa is a quarantine organism, not yet present in the UK. It has a wide host range that include Britain's native pedunculate oak and wych elm, as well as plane and red oak. The symptoms on infected trees are marginal leaf scorch (browning) often showing a yellow edge to the browned areas, wilting of foliage, dieback of branches and death.

Appendix VI – Trees for a Changing Climate

The table below gives brief details of trees suitable for street and parkland locations which are tolerant of summer drought and winter waterlogging. Further information on each of these trees can be obtained using the hyperlinks associated with the scientific names of each tree, or by visiting http://www.righttrees4cc.org.uk/.

Medium stature (10-20 m final height)			
Species	**Common Name**	**Region of Origin**	**Leaf Habit**
Acacia dealbata	Silver wattle	Australasia	Evergreen
Catalpa speciosa	Western catalpa	E. and Central N. America	Deciduous
Cupressus sempervirens	Italian cypress	S. Europe & Med.	Evergreen
Eucalyptus pauciflora		Australasia	Evergreen
Fraxinus ornus	Manna ash	S. Europe & Med.	Deciduous
Ginkgo biloba	Maidenhair tree	China	Deciduous
Juniperus chinensis	Chinese juniper	China	Evergreen
Juniperus virginiana	Pencil cedar	E. and Central N. America	Evergreen
Koelreuteria paniculata	Pride of india	China	Deciduous
Maclura pomifera	Osage orange	E. and Central N. America	Deciduous
Pinus armandii	Armand's pine	China	Evergreen
Pinus montezumae	Montezuma pine	W. N. America & Mexico	Evergreen
Pinus pinea	Stone pine	S. Europe & Med.	Evergreen
Pinus tabuliformis	Chinese pine	China	Evergreen
Pyrus calleryana	Callery pear	China	Deciduous
Quercus acutissima	Sawthorn oak	Korea	Deciduous
Quercus pubescens	Downy oak	S. Europe & Med.	Deciduous
Sassafras albidum	Sassafras	E. and Central N. America	Deciduous

Large stature (>20 m final height)			
Species	**Common Name**	**Region of Origin**	**Leaf Habit**
Carya cordiformis	Bitternut	E. and Central N. America	Deciduous
Cedrus atlantica	Atlas cedar	S. Europe & Med.	Evergreen
Cupressus arizonica var. glabra	Smooth Arizona cypress	W. N. America & Mexico	Evergreen
Cupressus macrocarpa	Monterey cypress	W. N. America & Mexico	Evergreen
Eucalyptus coccifera	Mount Wellington peppermint	Australasia	Evergreen
Eucalyptus globulus	Tasmanian blue gum	Australasia	Evergreen
Eucalyptus gunnii	Cider gum	Australasia	Evergreen
Eucalyptus johnstonii	Tasmanian yellow gum	Australasia	Evergreen
Gleditsia triacanthos	Honey locust	E. and Central N. America	Deciduous
Pinus ayacahuite	Mexican white pine	W. N. America & Mexico	Evergreen
Pinus jeffreyi	Jeffrey's pine	W. N. America & Mexico	Evergreen
Pinus nigra	Black pine	S. Europe & Med.	Evergreen
Pinus pinaster	Maritime pine	S. Europe & Med.	Evergreen
Pinus ponderosa	Western yellow pine	W. N. America & Mexico	Evergreen
Pinus sylvestris	Scots pine	N. Europe	Evergreen
Pinus thunbergii	Japanese black pine	Japan & Manchuria	Evergreen
Quercus coccinea	Scarlet oak	E. and Central N. America	Deciduous
Quercus ilex	Holm oak	S. Europe & Med.	Evergreen
Robinia pseudoacacia	Black locust, false acacia	E. and Central N. America	Deciduous
Salix alba	White willow	N. Europe	Deciduous
Taxodium distichum	Swamp cypress	E. and Central N. America	Evergreen

Glossary of Terms

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

Broadleaf species – for example, alder, ash, beech, birch, cherry, elm, hornbeam, oak, poplar, chestnut and sycamore.

Canopy / **Tree-canopy** - the upper most level of foliage/branches in vegetation/a tree; for example as former by the crowns of the trees in a forest.

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

Carbon sequestration - the removal of carbon dioxide from the air by plants through photosynthesis.

Crown – the part of a plant that is the totality of the plant's above-ground parts, including stems, leaves, and reproductive structures.

Defoliator(s) – pests that chew portions of leaves or stems, stripping of chewing the foliage of plants (e.g. Leaf Beetles, Flea Beetles, Caterpillars, Grasshoppers).

Deposition velocities - dry deposition: the quotient of the flux of a particular species to the surface (in units of concentration per unit area per unit time) and the concentration of the species at a specified reference height, typically 1 m.

Diameter at Breast Height (DBH) – the outside bark diameter at breast height. Breast height is defined as 4.5 feet (1.37 m) from the ground surface on the uphill side of the tree.

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

Ecosystem services - benefits people obtain from ecosystems.

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

Leaf area index - the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows.

Meteorological - phenomena of the atmosphere or weather.

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

Pathogen - any organism or substance, especially a microorganism, capable of causing disease, such as bacteria, viruses, protozoa or fungi.

Re-suspension - the remixing of sediment particles and pollutants back into the air, or into water by wind, currents, organisms, and human activities.

Stem cankers - a disease of plants characterized by cankers on the stems and twigs and caused by any of several fungi.

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

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

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

Tree dry-weight – tree material dried to remove all the water.

Endnotes

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[3] See Appendix I and http://www.itreetools.org/
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[8] Council of Tree and Landscape Appraisers (2001)
[9] Neilan/LTOA (2010)
[10] Southwood (1961), Kennedy and Southwood (1984), RHS (2012)
[11] https://www.forestry.gov.uk/london-itree
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[13] Santamour (1990)
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[17] Niinemets and Valladares (2006)
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[19] Committee on the Medical Effects of Air Pollutants (2010)
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[21] Nowak et al. (2006)
[22] Bolund and Hunhammar (1999)
[23] Jacob and Winner (2009)
[24] Based on an average UK household emission of 5 tonnes of CO_2 per year in 2012 (Palmer and Cooper 2013)
[25] Based on the number of households in Petersfield in 2011 (http://www.petersfieldsplan.co.uk/wp-content/uploads/2014/07/Navigus-Petersfield-Housing-report-final-report.pdf)
[26] DECC (2015)
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[28] RHS (2012)
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[32] https://www.buglife.org.uk
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[34] Tubby and Webber (2010); Wainhouse and Inward (2016)
[35] https://www.forestry.gov.uk/forestry/infd-9cden2
[36] https://www.opalexplorenature.org/treesurvey
[37] http://www.observatree.org.uk/about/volunteers/
[38] http://www.petersfieldtomorrow.co.uk/documents/PetersfieldBAP.pdf
[39] http://www.petersfieldsplan.co.uk/wp-content/uploads/2016/02/20160101-PNP-Main-Plan-Final.pdf
[40] See for example http://www.costen.co.uk/_photo_12319327.html#photos_id=12319328 and following images; http://www.francisfrith.com/petersfield/photos; Jeffrey (2013)
[41] https://www.woodlandtrust.org.uk/visiting-woods/trees-woods-and-wildlife/british-trees/common-non-native-trees/cypress/
[42] https://www.rhs.org.uk/advice/profile?PID=351

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[44] Sarajevs (2011); Eftec & Cascade Consulting (2013)
[45] HM Treasury (2015)
[46] Hirabayashi (2013
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