Understanding the value of Southampton's urban trees

Forest Research is the Research Agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research. The Agency aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, technical support and consultancy services.

Treeconomics is a social enterprise, whose mission is to highlight the value of trees and woodlands and to understand how trees improve our towns and cities. Treeconomics works with businesses, communities, research organisations and public bodies to achieve this.

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.

In association with:

SOUTHAMPTON CITY COUNCIL

UNIVERSITY OF Southampton

Citation

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Contents

Key definitions

Urban areas: are often defined by the presence of buildings, roads and railways; a centre of commerce, industry and entertainment; a preponderance of concrete and tarmac; atmospheric pollution; and a population which does not engage in agriculture. In England, urban and rural land use is defined by population density:

- Rural areas: settlements of less than 10,000 people.
- Urban areas: settlements of 10,000 or more people (RUC, 2011).

Southampton: is classified as 'urban with city and town' (class 4 of Defra's 2011 Rural-Urban Classification system) (Defra, 2014), with a population of 254,275[1]. It covers an area of 14,174 ha (Bibby & Brindley, 2013). For this study, we used an area of 5,019 ha for the core area of Southampton City. Southampton is the economic hub of the south coast and one of the largest cities in the southeast outside London (Harris, 2015).

Urban forest: is defined as 'all the trees in the urban realm – in public and private spaces, along linear routes and waterways, and in amenity areas. It contributes to green infrastructure and the wider urban ecosystem' (Doick et al., 2016).

Urban forestry: is defined as 'the management of trees for their present and potential contributions to the physiological, sociological and economic well-being of urban society' (Jorgensen, 1986).

i-Tree Eco: developed as the urban forest effects (UFORE) model in the 1990's to assess impacts of trees on air quality. It has become the most complete tool available for analysing the urban forest as it includes the most detailed results on the structure and functions of trees. It has been used in over 100 cities globally by urban foresters, communities and businesses to manage urban forests effectively (Doick et al., 2016).

[1] Southampton City Council Mid year population estimate (SCC 2016a)

Executive summary

Urban trees collectively form a forest resource that provides a range of benefits to human populations living in and around them. Termed ecosystem services, these shared benefits provided by the urban forest help to offset many problems associated with increased urban development. Trees improve local air quality, capture and store carbon, reduce flooding and cool urban environments. They provide a home for animals, a space for people to relax or exercise, and can improve social interrelation in communities. These direct benefits to the people who live, work and rest close to Southampton are the focus of this report. Using a well-known assessment and evaluation model – i-Tree Eco v6.0 – the urban forest benefits are herein given a value so that health and wellbeing, and the introduction of biological diversity in an otherwise austere, hard architectural environment, can be appropriately resourced to ensure that the benefits are maintained and where appropriate enhanced.

Ecosystem service benefits are directly influenced by the management actions that impact upon the overall structure and vitality of the urban forest resource. Gaining an accurate knowledge of the structure, composition and distribution of trees is a first step to understanding the make-up of the urban forest. Assimilating information from a survey can develop a baseline from which to understand the threats, set goals and monitor progress towards optimising the resource. By measuring the structure of the urban forest, through recording information about the tree species present, their size and condition, the benefits can be determined and the value of these benefits calculated and, in some cases, expressed in monetary terms.

By putting a monetary value on these benefits provided by the urban forest, this can increase the profile of the forest, and so help to ensure its value is maintained and improved upon. This was achieved by undertaking an i-Tree Eco v6 survey in summer 2016. The data provides detailed information on the forest's structure and its composition. It also demonstrates that residents living in Southampton benefit significantly from urban trees: in terms of avoided water runoff, carbon sequestration and the removal of five types of air pollutants we estimate that Southampton's urban forest **provides citizens with ecosystem services worth more than £1.29 million per year.**

This huge value is still just an underestimate. It excludes the many ecosystem services provided by trees that are not currently assessed by i-Tree Eco, including cooling local air temperatures and reducing noise pollution, and so **this value is a *conservative estimate*** of the ecosystem services provided.

This study captures a snapshot-in-time. It does not consider how the urban forest has temporally or physically 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 the urban forest of Southampton should change in the future and how to ensure that it is resilient to the effects of a changing climate. This study goes a long way to providing the necessary baseline data required to inform decision making for the future. The study was funded by the University of Southampton Excel internship programme and carried out by Southampton City Council, Treeconomics, Forest Research and students and staff from the University of Southampton.

Southampton i-Tree Eco Headline Facts and Figures		
Total number of trees (estimate)	267,500	
Total tree canopy cover	18.5%	
Top three most common species	English oak, Sycamore, Common holly	
Proportion of small, medium, large trees (by dbh)	45%, 44%, 11%	
Amenity value of the urban forest (CAVAT)	£3,215 million	
Replacement cost of the urban forest (CTLA)	£282 million	
Proportion of trees on vacant land (%)	10%	
Values		
Carbon storage	100,583 tonnes	20 tonnes per ha
Net carbon sequestration (per annum)	2,684 tonnes	534 kg per ha
Air pollution removal (per annum)	90 tonnes	18 kg per ha
Avoided runoff (per annum)	94,894,990 litres	18,907 l per ha
Total benefit (per annum; excl. carbon storage)	£1.29 million	£256 per ha

Key results

The urban forest of Southampton in 2016:

- had over **267,000 trees**, resulting in an average **urban tree density of 52 trees per hectare**, this is below estimates for other areas in the UK.
- had an **18.5% urban tree cover**, equal to an area of 929 ha. The trees were primarily found in **parks, residential land** and on **vacant land.**
- included **103 tree species** across ten land use categories.
- had oak, sycamore and holly as the most common tree species.
- was mostly under public ownership (51%) and native and deciduous trees provided the most benefit.

Southampton's trees:

- intercept an estimated **95 million litres of water every year**, equivalent to **£142,894** in sewerage charges avoided (2016 prices).
- remove an estimated **90 tonnes of airborne pollutants** each year, the removal of which is worth more than **£533,720** in damage costs (2016 prices, excluding CO and O3).

- remove an estimated **2,684 tonnes of carbon** from the atmosphere each year, worth **£609,327** (2016 prices).
- store an estimated **100,583 tonnes of carbon**, worth **£23.4 million** in 2016.
- had an asset value of **£3,215 million** in 2016, an evaluation based on public amenity.

Key conclusions

- Species mix in the urban forest should be diversified to build resilience to climate change, to the threats posed by emerging pests and diseases and to improve ecosystem service provision by Southampton's urban trees.
- Southampton's trees should be managed to increase the number and diversity of mature large and small stature trees as they proportionally provide more ecosystem services. In particular, mature trees should be protected on vacant land that is vulnerable/susceptible to development.
- 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 forest needs to be aligned to the strategic planning of the urban forest to maximise these benefits through reviewing the City Action Plan and Green Grid Strategy.
- Southampton City Council aims to increase canopy cover by 6.5% to **25% canopy cover**. This could be achieved through street planting, mandatory planting of trees on new developments in Southampton, and by ensuring that a proportion of existing trees are maintained and allowed to grow to maturity.
- Assessment of the urban forest should be repeated in five years to assess change and monitor progress in line with any future urban forest management strategies. Logically, this assessment should be an i-Tree Eco study to ensure consistency and comparability.

Introduction

This report represents the first comprehensive study on Southampton's urban trees. It provides a baseline of the urban forest across the city, which will help to inform decision-makers on how best to manage it.

Ecosystem services, which are benefits that people obtain from ecosystems (MEA, 2005), are a vital element to human society. Urban forests provide a range of such benefits on different spatial scales, including climate regulation, air pollution removal, flooding protection and habitat provision (Figure 1). To understand urban forests better, large-scale assessments can be carried out. The i-Tree Eco model, developed by the US i-Tree Cooperative[2], is one such method of assessment. It has been rigorously tested and used in 100 cities globally. It has been rated as fit-for-purpose in valuing UK green infrastructure (Natural England, 2013).

The rest of the Introduction covers three areas:

- Natural capital and ecosystem service provision.
- Recent green infrastructure studies in Southampton prior to the current study.
- Policy relevant to the study.

The core concepts of natural capital and ecosystem service provision are necessary in order to understand the i-Tree approach to urban forest assessment at the local level. The previous studies, all of which are in connection with Southampton City Council, are provided to act as a foreground to the main results of the report. Relevant policy at the national, regional and local scale is identified to showcase the importance of urban forests at all levels of government.

[2] i-Tree Co-operative: an initiative involving USDA Forest Service, Davey, Arbor Day Foundation, the Society of Municipal Arborists, International Society of Arboriculture and Casey Trees

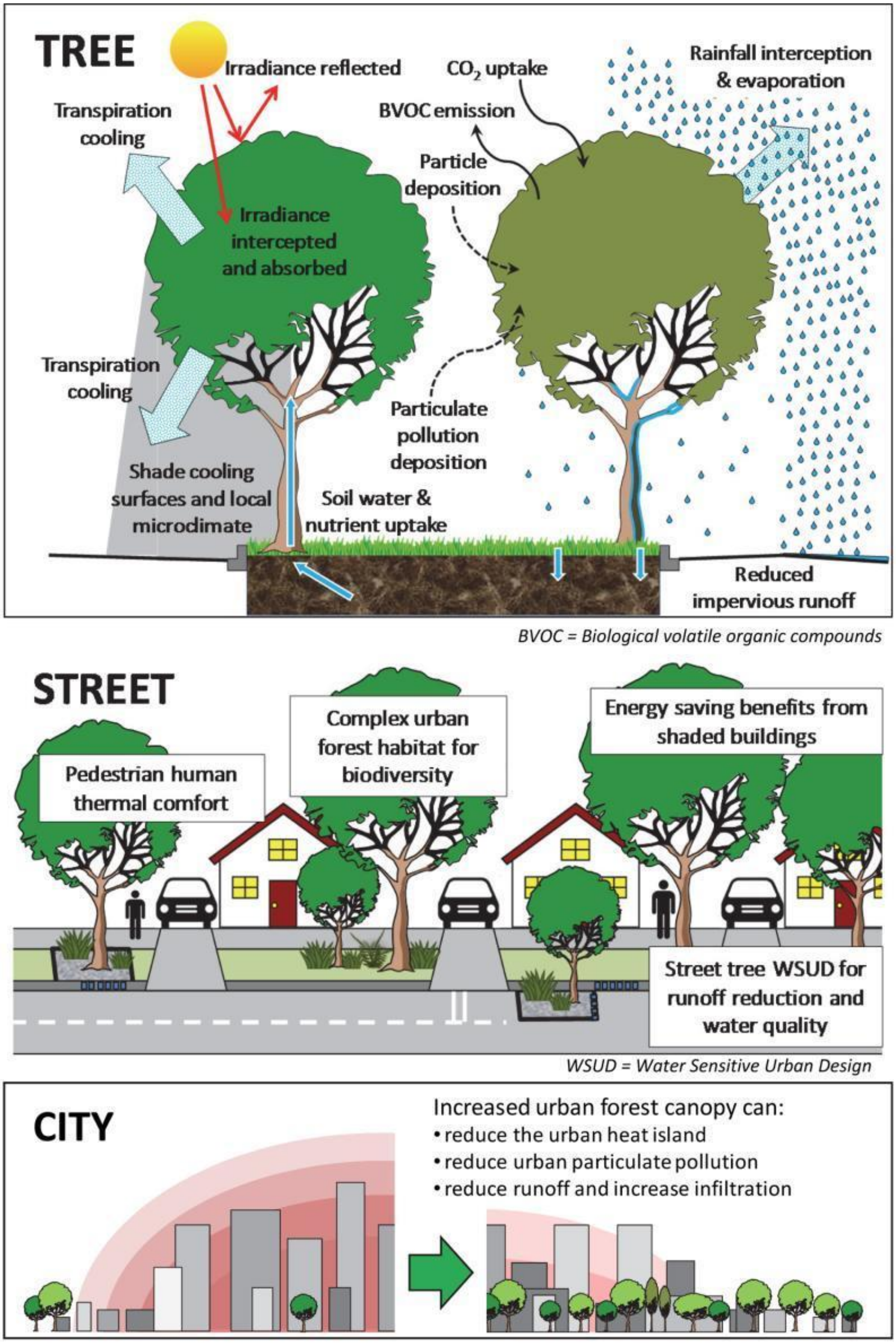

Figure 1. Urban forest ecosystem services at different scales (Livesley et al., 2016)

Natural capital

Natural capital is the elements of nature that directly or indirectly produce value to people (NCC, 2017). This can be in the form of goods, benefits and services. Until relatively recently, natural capital has not been fully accounted for in decision making and thus undervalued. Through current understanding of the numerous services that the environment provides, it is essential to prioritise and value it (UK NEA, 2011; TEEB, 2012).

Within the past decade or so, frameworks have been established to more fully comprehend the goods and services that ecosystem services can deliver, typically categorised under provisioning, supporting, regulating and cultural services (MEA, 2005; UK NEA, 2011). Quantifying and assessing the value of such services can foster change in people's perceptions of the urban forest, and thus in decision-making.

Southampton City Council provides a suitable quote which sums up the benefits:

> *Gardens, woodlands, parks, and waterways have an integral part to play: they can soak up rainwater through natural drainage, improve the air quality by trapping particles, cool the city down through providing shade and moisture evaporation and provide habitat for wildlife. Added to the health benefits for our communities and residents and the role it plays in making Southampton an attractive place to live, the wide network of open green spaces that already exist throughout the heart of Southampton are the city's most important asset – its green lungs. (SCC, 2011)*

Southampton studies

A few Southampton studies have already started researching the urban forest. For example, an i-Tree Eco study conducted by Chan (2014) assessed 110 trees in Watt (West) Park in the town centre and found the trees to be worth more than £300,000 (according to the CTLA v.9 approach)[3]. Another key study also undertaken in 2014 highlighted the change in land cover of front gardens, from permeable to impermeable. Warhurst (2014) focused on 8 flooding hotspots identified by the local council. Within these areas, impermeable cover increased by 22.5% over the 20-year study period (1991–2011). This required attenuation[4] storage volumes to increase by 26.2% on average. As such, there is a potential increase in flooding risk due to the conversion of front gardens to car parking spaces. Another study using the i-Tree software looked at how specific tree species could tackle air pollution on Southampton's busiest roads (Cohen, 2014). Other relevant studies in Southampton include the development of green space factors for use in planning decisions (Farrugia et al., 2013), and the economic valuation of green walls (Collins et al., 2017).

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[3] The replacement cost calculated using i-Tree Eco (CTLA) is a management tool for looking at what it might 'cost' to replace a tree with another tree. It is different from the CAVAT method which adds an amenity 'value'.

[4] The process of water retention on site and slowly releasing it in a controlled discharge to a surface water or combined drain or watercourse (SWS, 2017)

The current (2016) i-Tree study therefore adds to the knowledge already collected to improve understanding of the benefits derived from Southampton's urban forest.

What i-Tree can and cannot do

Many ecosystem services provided by urban trees are not quantified by i-Tree Eco. The value of Southampton's urban forest should be recognised as a **conservative estimate** of the complete amount of benefits available.

- The v6 i-Tree Eco model provides a snapshot-in-time picture on size, composition and condition of an urban forest. Only through comparison to follow-up i-Tree Eco studies, or studies using a comparable data collection method, we can assess how the urban forest is changing over time.

- i-Tree Eco requires air pollution data from a single air quality monitoring station and the data used therefore represents a city-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 an urban forest, 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;

    - 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; and

    - guidelines on species composition and size class distribution for a healthy resilient urban forest.

Policy context

The Government's Forestry and Woodland Policy Statement (Defra, 2013) recognises the key role of the urban forest in engaging people with trees and woodlands on their doorstep. It notes the importance of valuing our urban trees, using tools such as i-Tree. Urban forests can also contribute to meeting objectives 1 and 4 of Defra's strategy to 2020. These involve a cleaner, healthier environment (1) and a nation protected against floods and other hazards (4) (Defra, 2016). For southern England, the Green Infrastructure Strategy for Urban South Hampshire (2010-2026) deals with urban forests. In this strategy, a multifunctional green network of South Hampshire's distinctive local environments needs to be developed to ensure they can adapt to climate change and are managed and valued as part of sustainable, prosperous and healthy lifestyles.

At the level of Southampton, there are many policies in place directly or indirectly involving the urban forest (Table 1). The City Centre Action Plan specifically focuses on green infrastructure through policy AP12 Green Infrastructure and Open Space. This means the true value of our natural resources is embedded into decision-making at all levels. The plan is also set to improve accessibility to open spaces through creating a network of strategic pedestrian and cycle links and facilitating a Green Grid of routes and spaces throughout the centre. This would link existing neighbourhoods, destinations, open spaces and the waterfront. The Green Grid will include tree planting, landscaping, green spaces and/or green walls. Although this policy only relates to the city centre area, its approach will soon be rolled out across the rest of the city in the City-wide Local Plan. Scott et al. (2017) showed AP12 has multiple connections to new developments and public open space (AP13), energy policy (AP14) and flood resilience (AP15).

Table 1. Summary of Southampton policy linked to the urban forest

Policy	**Linkage to the urban forest**
City Centre Action Plan (Harris 2015)	AP12-Intended to secure increases in green infrastructure through the development process. Green Grid development
Southampton Council strategy (2016-2020) (SCC 2016b)	Outcomes 3 (People live safe, healthy, independent lives) and 4 (Southampton is a modern, attractive city where people are proud to live and work)
Southampton Local Flood risk management strategy (2014-2019)	Tree planting as part of SuDS (Sustainable Drainage Systems) through the uptake of surface water and slow release into our waterways
Low Carbon City Strategy (2011-2020)	Strengthen biodiversity in the city- improving the way Southampton links together the rich patchwork of diverse, living green spaces and tree-lined streets in the city.
Air Quality Management Plan (forthcoming)	Tree planting to counteract air pollution

Opportunities

This report can help Southampton plan for these policy objectives by providing a baseline on the urban forest structure and its benefits. In doing so, this can support decision makers in their aim to achieve:

Social objectives:

- Legal: target effort to deliver urban and national planning obligations (see above).
- Policy: reinforces policy to protect and expand all aspects of Southampton's urban forest including under both private and public ownership.
- Evaluation: demonstrate the quality of life benefits being gained through urban greenspace in line with local authority objectives.
- Education and advocacy: raise the profile of the urban forest as a key component of green infrastructure that provides many benefits and services to those who live and work in Southampton.

Economic objectives:

- Manage Southampton's urban forest as an asset, with appreciable return.
- Retain the status of one of Southern England's economic hubs by industry choice as an attractive place to work and live.

Environmental objectives:

- Resilience:
  - Redress imbalance in species mix and age composition profiles; such changes would also help create a forest that is more resilient to the impacts of climate change.
  - Risk management: identify risks to the tree population such as through even aged populations, pests and diseases, and to plan accordingly.
- Recreation:
  - Develop the Green Grid plan for robust green networks to help Southampton become a more sustainable urban ecosystem in the future linking together natural, semi-natural and man-made open spaces to create an interconnected network that provides recreational opportunities.

Quality of life: provision of green space to support mental health and wellbeing through near nature experience.

Links

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 (the website of the Arboricultural Association), www.treeconomics.co.uk or www.forestry.gov.uk/fr/itree.

For further details on Tree canopy cover in towns and cities across the UK see: www.urbantreecover.org

The identification, measurement, mapping and caring for trees in the urban environment are all areas of significant opportunity for members of the general public and community groups to become 'citizen scientists'. Interested readers are referred to Treezilla: the Monster Map of Trees (www.treezilla.org) to learn more and to get involved in mapping and valuing urban trees.

Methodology

i-Tree Eco uses a plot-based method of field sampling. The recorded data was then extrapolated to represent the whole study area. Each circular plot measured 404 m^2 or 11.4 m radius. The final number of plots surveyed was 414 (Figure 2). As a result, for the area of Southampton City (5,019 ha), a plot was measured for every 12 ha. This is a much higher density of plots than for any other i-Tree Eco study in the UK[5].

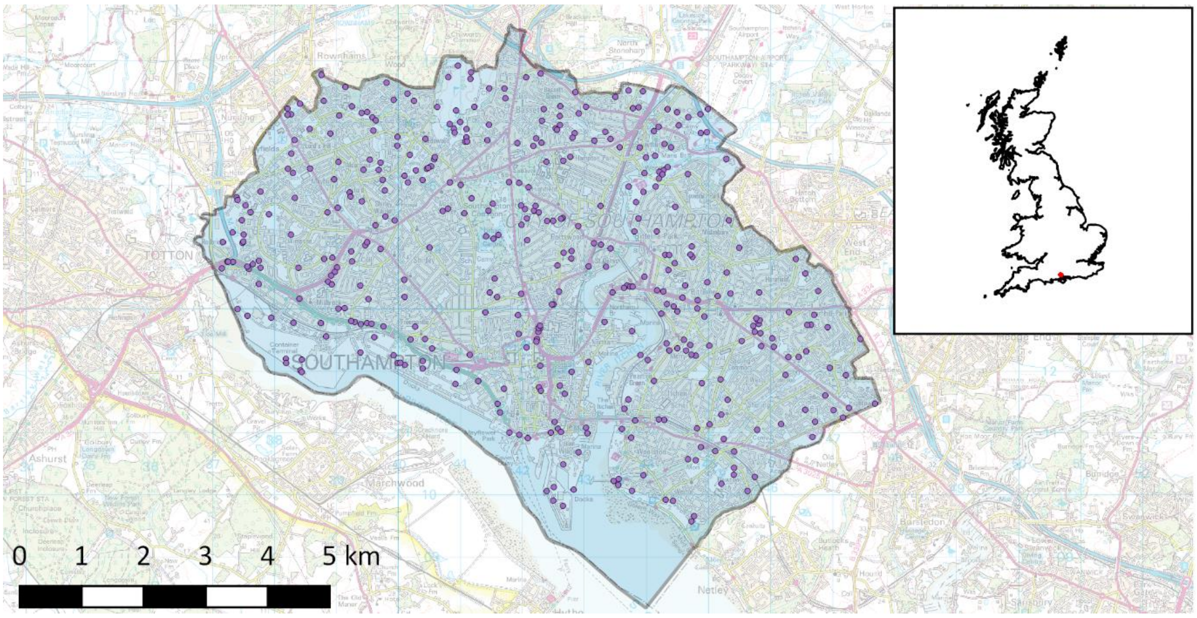


Figure 2. Plots in Southampton

The proportion of plots falling into each of the different land uses is given in Figure 3.

[5] The purpose of surveying >400 plots when other cities in the UK have tended to use ~200 plots was to facilitate subsequent investigations into sampling density effects on i-Tree Eco results.

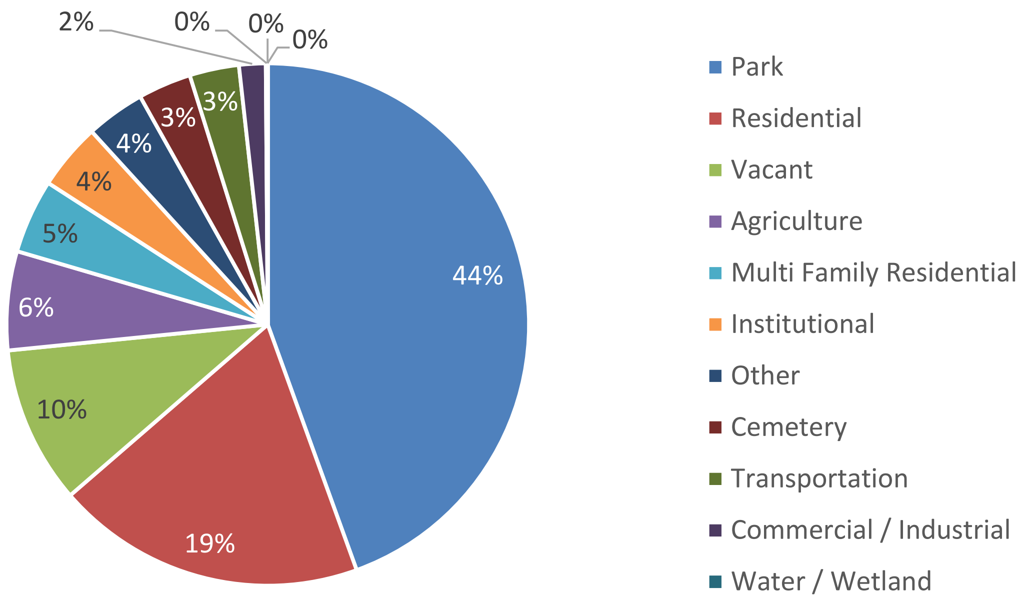


Figure 3. Land uses of surveyed plots (%) (for a definition of land-uses see Appendix 1: Table A1)

The standardised field collection method from i-Tree Eco v6.0 was used, as outlined in the i-Tree Eco v 6.0 Manual (i-Tree, 2017). The software has recently been adapted for use in the United Kingdom, including incorporation of local weather station data and our pollution information.

The field data was collected during the leaf-on season in July and August 2016. The field data was modelled using the local climate and air pollution data in-built within i-Tree v.6 (dated from 2013) to produce estimates of ecosystem service provision. The inputs, information collected at each of the plots, are listed in Table 2. The outputs generated are listed in Table 3. Data was post-stratified in order to analyse differences in results. This was according to: origin, whether the tree was evergreen or deciduous and the Index of Multiple Deprivation (IMD) category (DCLG, 2015). The IMD index contains information on different levels of deprivation according to location (at the lower super output area (LSOA) scale).

Table 2. Key information recorded for each plot. N.B. Trees were only measured if the stem diameter was above 7 cm. Trees below this size were not considered as part of the survey following standard forestry practice. Shrubs were recorded even if less than 7 cm, as well as the size and dimensions of the shrub masses. Shrubs were identified to the level of either deciduous or evergreen.

Plot Information	**Tree information**
○ Reference objects for plot centre ○ Land use type ○ Percent tree cover ○ Percent shrub cover ○ Percent plantable space ○ Percent groundcover type	○ Species ○ Stem diameter ○ Total height ○ Live top height ○ Height to crown base ○ Crown width (N-S, E-W) ○ Percent canopy condition ○ Percent foliage missing ○ Crown light exposure ○ Percent impervious under tree area ○ Percent shrub under tree area ○ Street tree characterisation ○ Species life expectancy

*Table 3: Outputs of the study *-Additional outputs from the authors*

Urban Forest Structure and Composition	Land use and ground cover, species and size class distribution, species dominance, % leaf area by species and canopy cover, Tree diversity
Ecosystem Services	Air pollution removal by urban trees for CO, NO_2, SO_2, O_3, $PM_{2.5}$ and value in £ for the removal of NO_2, SO_2 and $PM_{2.5}$ Annual carbon sequestered and value in £ Rainfall interception and avoided sewerage charges value in £
Replacement Cost	Amenity value in £ using a CAVAT (Capital Asset Value for Amenity Trees) assessment Replacement cost in £ using a CTLA (Council of Tree and Landscape Appraisers) assessment Current carbon storage value in £
Pest and Diseases*	Risk matrices Most prevalent pest and diseases
Habitat Provision*	Pollinating insects

Description of amenity value

CAVAT has been developed in the UK and has been used by councils to support planning decisions. 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. The CAVAT Quick Method was chosen to assess the trees in this study. 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 within Southampton or the wider UK. A risk matrix was devised for determining the potential impact of priority pests and diseases, should they become established in the urban tree population of Southampton. 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 is not available for all the tree/shrub species encountered in Southampton.

Calculations

Table 4: Summary of calculations used in the study

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 US externality cost prices ($USEC) or the UK social damage costs (£UKSDC) where available (per metric tonne)	
	CO O_3 NO_x SO_2 $PM_{2.5}$	$984 $6,930 £12,205 £1,956 £33,713

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 Southern Water's 2016/17 metered water charge of £1.310 per m^3.
Carbon storage & sequestration values	The baseline year of 2016 and the respective 2016 DECC value of £63 per metric ton.
Replacement cost (amenity valuation)	Using the CAVAT (Capital Asset Value for Amenity Trees) method, and the CTLA (Council of Tree and Landscape Appraisers) method.

Comparison with other UK i-Tree Eco Studies

Location	**Source**
Edinburgh	Doick et al. 2017
London (Inner London)	Rogers et al. 2015
Torbay	Rogers et al. 2012
Tawe catchment (Swansea)	Doick et al. 2016

Results and discussion

Canopy cover

Based on the sample plots, the canopy cover for Southampton is 18.5% (Table 5). This equates to an average density of about 52 trees per hectare. This corroborates with the LiDAR survey (2013), which recorded 20.4% canopy cover. However, this was spread over a larger area (over 7,000 ha rather than the 5,019 used in this study). Similar figures of 19.8% and 22.8% were obtained using the i-Tree Canopy tool, with the former based on the 'urban' boundary of Southampton, and the latter based on the boundary of the local authority (Doick et al., 2017). Tree canopy cover for Southampton has been compared with other i-Tree Eco surveys in the UK (Table 5).

Table 5. Comparing Southampton to other i-Tree eco surveys

	Southampton	Torbay	Inner London	Tawe catchment	Edinburgh
Study area size (ha)	5,019	6,374	31,012	6,995	11,468
Sample density (one plot per […]ha)	12	26	155	28	57
Canopy cover (ha)	929	752	5,582	1,119	1,950
% Canopy cover	18.5	12	18	16	17
Average number of trees per ha	52	105[6]	51	76	62

Ground cover

In 2016, ground cover in Southampton consisted of approximately **49% permeable materials**; the remainder consisted of non-permeable surfaces such as tar (asphalt), concrete and cement (which contribute to heating of the urban environment). 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 comparison to other studies, this is similar to Inner London (46%), but less than Torbay (>60%), Edinburgh (55%) and the Tawe catchment (53%).

[6] The Torbay report records 128 trees per hectare, however the survey included trees with <7cm DBH which have been removed and the value recalculated for consistency in this table.

Urban forest structure

Species composition

Southampton has an **estimated tree population (>7cm DBH) of 267,500**. It is not surprising that, roughly speaking, there is just less than 1 tree for each person living in the town. This is because Southampton is one of the more densely populated cities in the UK (HCC, 2013). The five most common species are: oak, sycamore, holly, silver birch and beech. The top twelve species accounts for 68.2% of the population (Figure 4). Most trees in Southampton occur in park land (44%), residential land (19%) and vacant land (10%) (Figures 5a-5c).

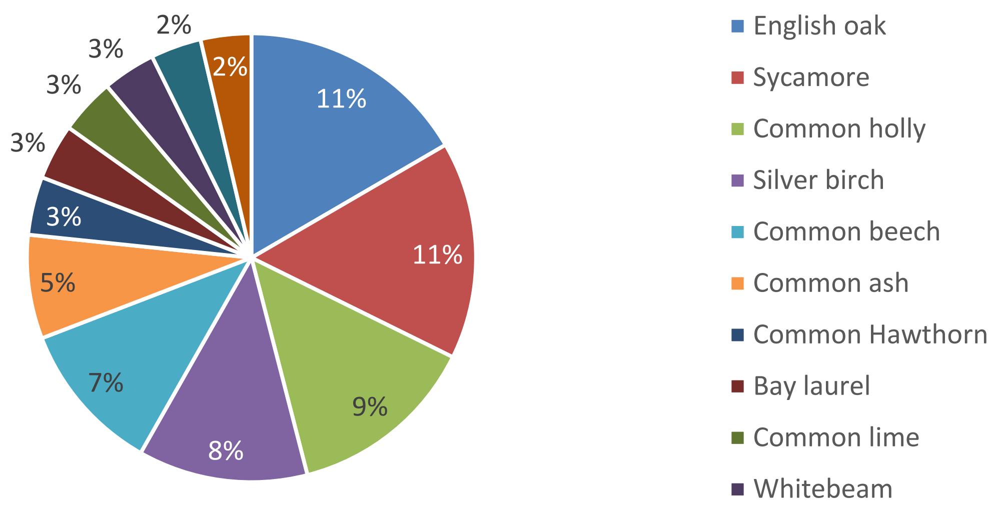


Figure 4. The twelve most common tree species recorded in the Southampton survey.

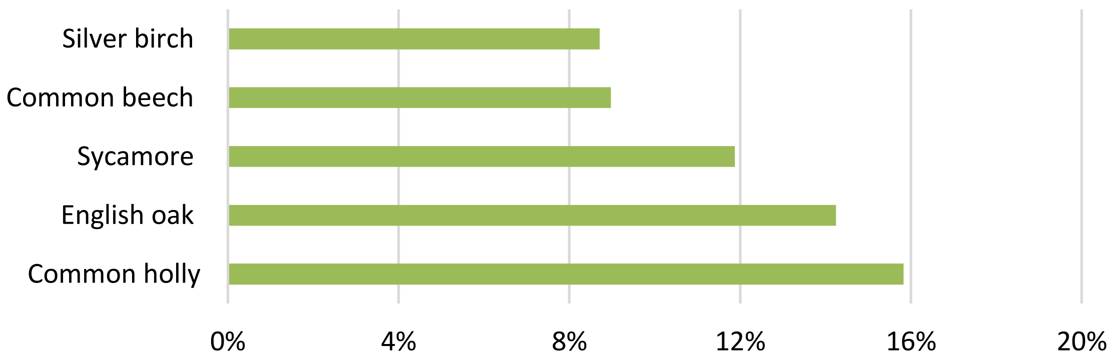


Figure 5a. Top 5 species in the Park land use

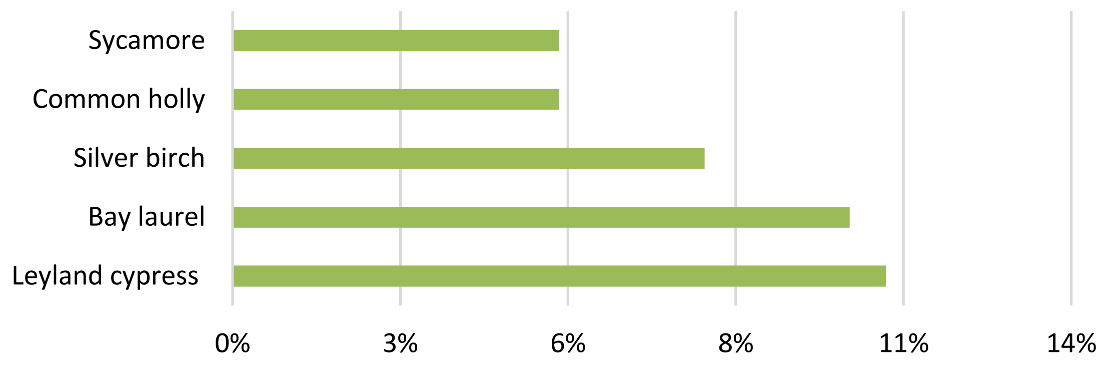


Figure 5b. Top 5 species in the Residential land use

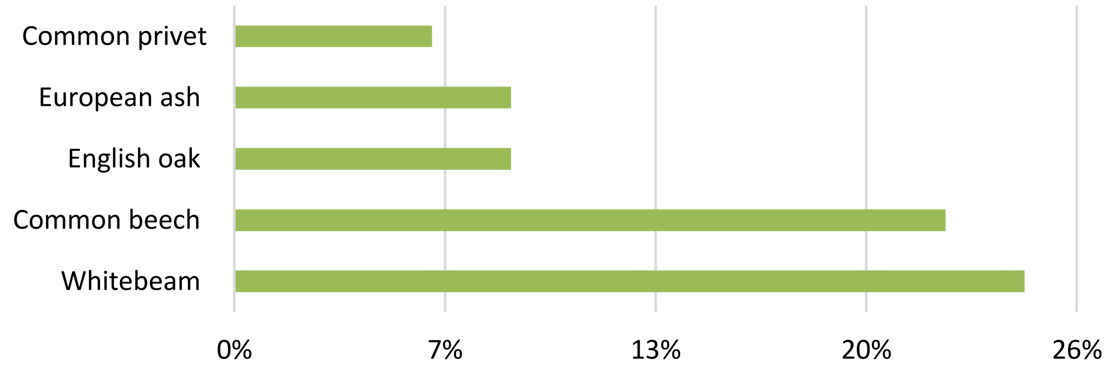


Figure 5c. Top 5 species in the Vacant land use

Just over half (51%) of Southampton's trees are in public ownership (comprising park, cemetery and transportation land uses) whilst 44% is in private[7] ownership. The remainder comprises 'other' land uses, such as green areas between residential housing, which may be public or private. For those trees under private ownership, there is a degree of risk for planning the urban forest due to its vulnerability unless protected or in long term stewardship (e.g. a woodland grant scheme). Educating on the significance of this shared resource can be a way to mitigate this risk, beyond tree protection.

Species diversity

A total of 103 tree species were encountered during the study. This is similar to Torbay (102 species) but lower than inner London (126 species). 65% of the tree species were deciduous, compared with 31% evergreen (Figure 6). Santamour (1990) recommended that for urban forests to be resilient to pests and diseases, no species should exceed 10% of the population, no genus 20% and no family 30%. Whilst this rule of thumb is a good starting point, presenting something better than the status quo, it is only a guideline, based on experience rather than data (Kendal et al, 2014). Santamour also

[7] Private includes: residential, multi-residential, golf-courses, institutional, commercial, and agriculture land uses.

acknowledged that this rule would not afford good protection against insects with a broad host range such as Asian Longhorned Beetle. Finally, whilst Santamour applied the rule to stem count (population), Ambrose (2016) suggests that it may be more useful and workable to apply the rule using a basal area or canopy metric to better measure any impact.

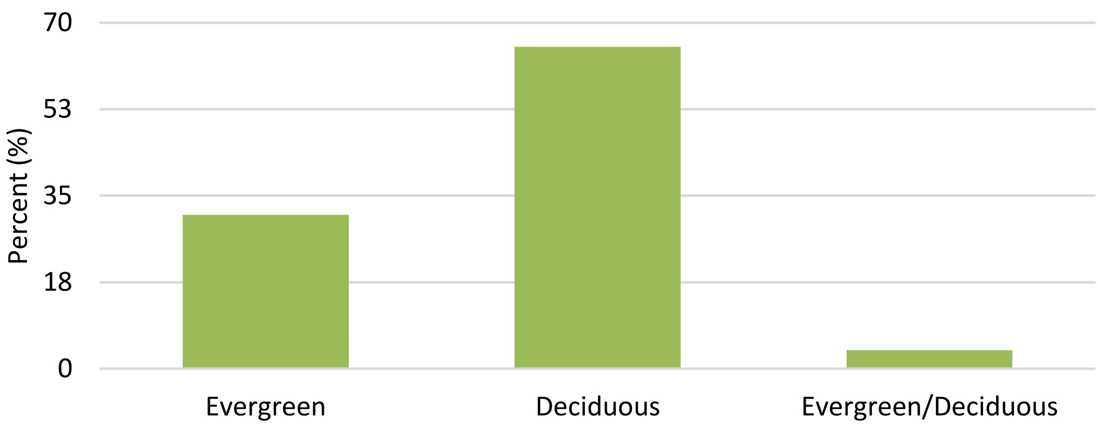


Figure 6. Percentage of deciduous vs evergreen tree species. NB. The E/D bar shows species which can be either

Table 6 outlines the top three species, genus and family frequencies in the Southampton survey.

Table 6. Frequencies of the top 3 species, genera and families

	1st		**2nd**		**3rd**	
Species	English oak	11.33%	Sycamore	10.71%	Common holly	9.34%
Genus	Quercus	11.41%	Acer	11.41%	Betula	9.06%
Family	Rosaceae	15.89%	Cupressaceae	8.41%	Sapindaceae	6.54%

The diversity of tree species, i.e. the number of different species present in a population and their numbers, is important because diverse populations are more resistant to pests and diseases (Johnston et al., 2011). The diversity of populations can be calculated using the Shannon-Wiener index. This is a measure of the number of different species, considering whether the population is dominated by certain species. The mean diversity score of Southampton's urban forest is 3.6 according to Shannon-Wiener index. While the mean for Southampton is on par with that reported for other cities – e.g. Edinburgh (3.2), Tawe (3.0), Torbay (3.3) and Inner London (3.7) – diversity varied with land use type, ranging from 2.1 in transport areas to 3.6 in residential areas (Figure 7).

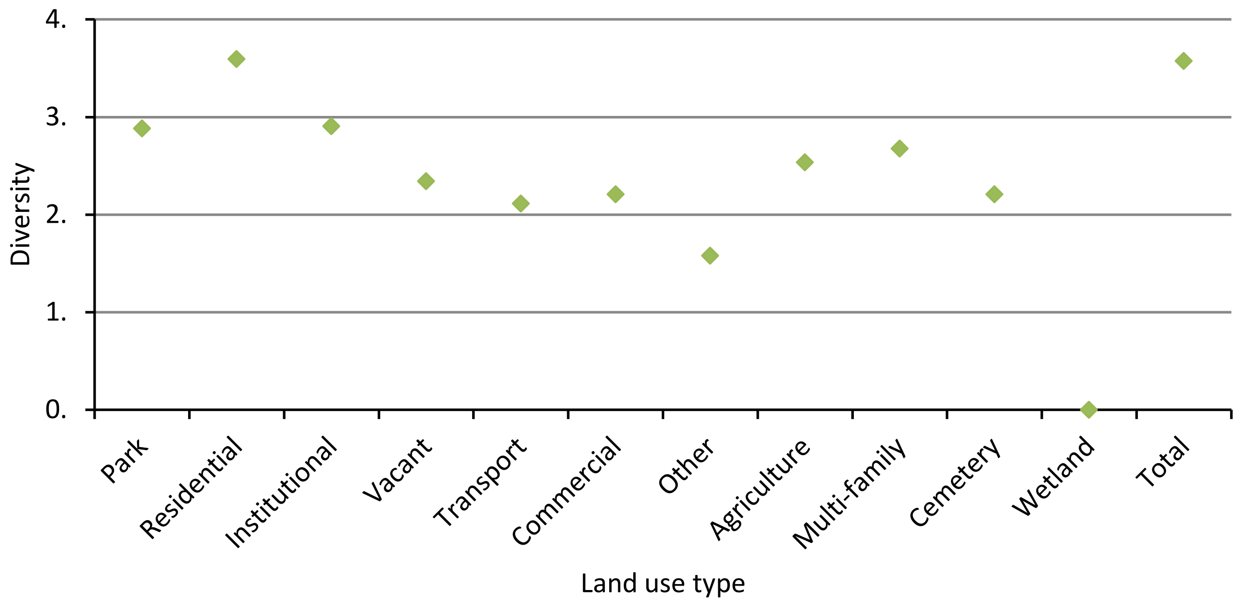


Figure 7. Diversity score by land use type (note: only one tree was recorded for Wetland)

Recommendation 1 – Increase species diversity

Southampton has on average a higher tree diversity compared with other i-Tree Eco surveys undertaken in the UK. There is a small over reliance on oak and sycamore, but the remaining species frequencies suggests it is within the recommendations suggested by the Santamour (1990) study.

Selecting trees to broaden the variety of species and increase the diversity offer of Southampton's urban forest will also increase the resilience to the impacts of a changing climate, whilst also increasing the public amenity value and offering broader support to biodiversity.

The greatest diversity of trees is found on residential land, institutional land and parkland. Influencing residential selection of trees is challenging because it is owned by multiple individuals with different land use objectives. Working to their own interests the tree resource is ultimately decided by what individuals choose to plant. Such tree selection is likely based upon decisions that impact amenity, wildlife value, shade or otherwise shelter and screening provision for the property. Benefits for the wider community are less likely to feature as a priority. Thus, there is a need for regulatory control for important amenity trees, such as through the planning system and, specifically through the use of Tree Preservation Orders for significant trees. However, there is also a need for education and outreach.

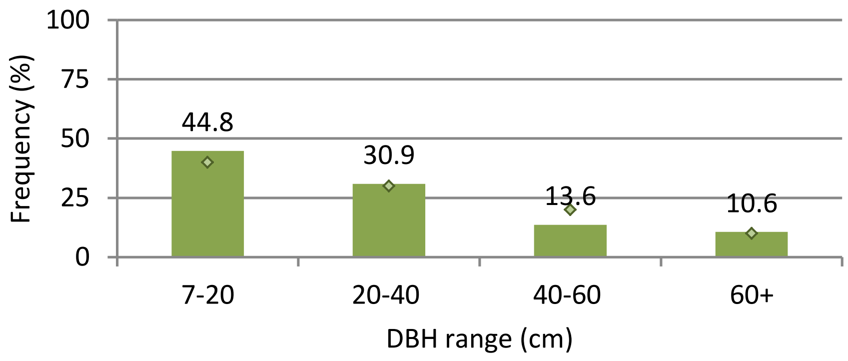
Southampton City Council could pursue such a role alongside initiatives by charities, community groups and other organizations interested in trees and green infrastructure.

Commercial and institutional land (e.g. Southampton and Solent University), meanwhile, are typically highly managed areas of the urban landscape. This land therefore has the potential to introduce a diversity of new species through considered selection, underpinned by institutional education or policy to form a community of professional practice.

Size class distribution

Size distribution is important for a resilient tree population. Large, mature trees offer unique ecological roles not offered by small trees (Lindenmayer et al., 2012). 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 diameter breast height (DBH) <20cm accounts for 45% of the total tree population in Southampton (Figure 8a). The number of trees in each DBH class then declines successively, where trees with a DBH >60 cm make up 10.6% of the tree population.

8a)



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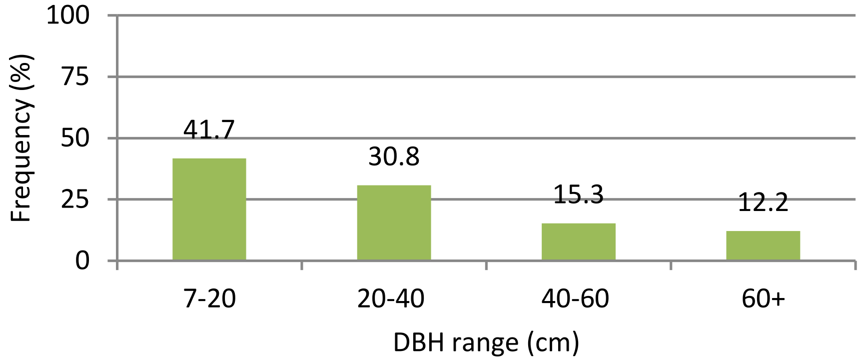

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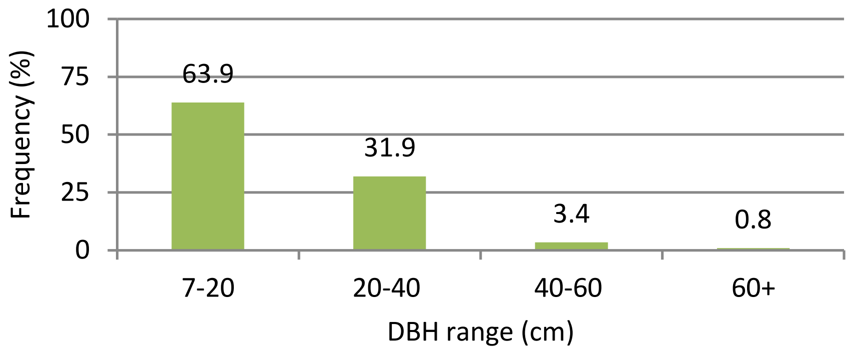

Figure 8a) DBH range of all trees encountered in the Southampton survey; b) Encountered, with small stature[8] trees removed from the analysis; c) Encountered, with large stature[9] trees removed from the

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[8] Small stature trees are defined as trees that do not normally attain height greater than 10 m

[9] Large stature trees are defined as trees that attain a maximum height greater than 10 m

analysis (with data values shown for clarity). Diamonds represent recommended frequencies for that DBH class as outlined by Richards (1983) – i.e. 40%, 30%, 20%, 10%[10].

Analysis of the large stature trees shows that 60 cm+ diameter trees account for 12.2% of the tree population (Figure 8b), which, though higher than the 10% value suggested by Richards (1983) for street trees, is far below the 30% suggested by Millward & Sabir (2010) as necessary to ensure a healthy stock of trees across the urban forest as a whole. This suggests that the population of large stature trees is comprised of a high proportion of immature trees. Analysis of only the small stature trees is shown in Figure 8c. These trees do not attain large stature and therefore there are high numbers of these trees in the lowest DBH class. However, approximately 32% is in the 20-40 cm DBH class, suggesting a good population of mature small stature trees in Southampton.

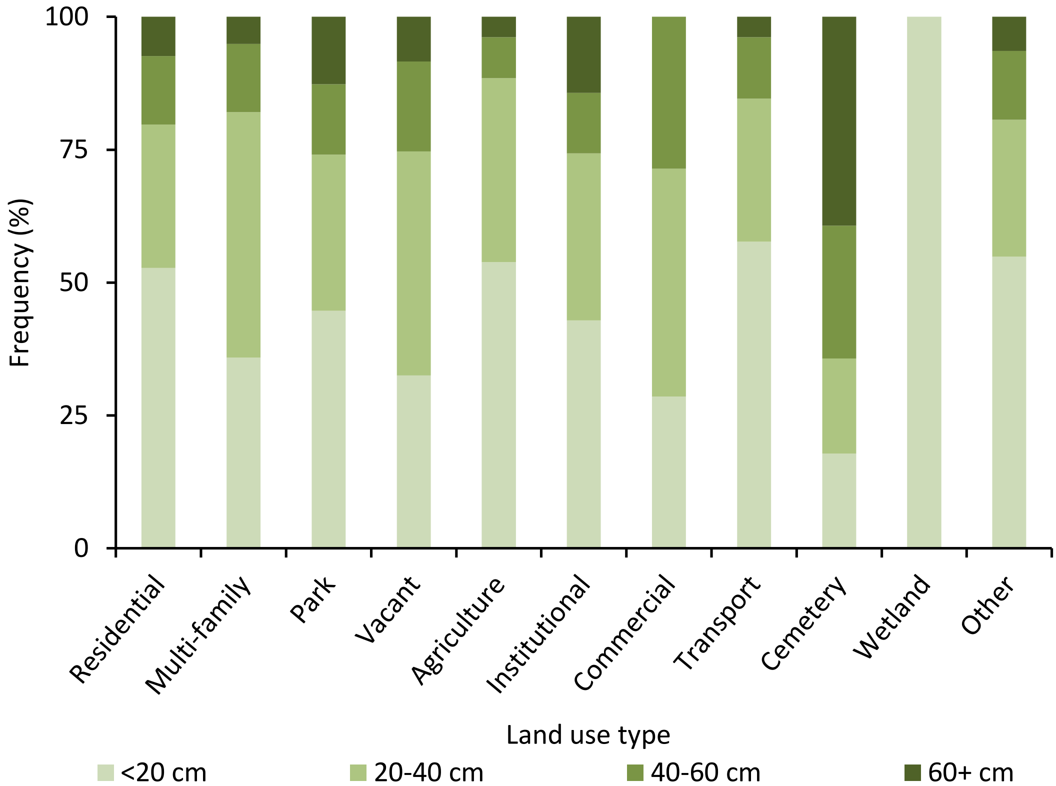


Figure 9. DBH by land use type (note: only one tree was recorded for Wetland)

Small trees (<20 cm DBH) were highest in proportion on wetland, transportation and agricultural land. Large trees (>60 cm DBH) were highest in proportion in cemeteries, institutional land and parks (Figure 9). DBH can be a good indicator of tree benefits. The larger trees typically lead to more benefits. Shown in Table 7, there is a higher percentage of larger trees in the public domain compared with private.

[10] It should be noted that the recommended frequencies of Richards (1983) relate only to street trees and not to the urban forest as a whole. More recently, Millward & Sabir (2010) proposed the following 'ideal distribution' for an urban forest: 40% within a DBH class of 0–15 cm; 30% from 15–60 cm; 25% in class 60–90 cm; and 5% classified as 90 cm and above.

Table 7. Proportion of trees by private and public land

Type	Description	Trees measured with a DBH of 40 cm or over (%)
Private	Residential, MF residential, vacant, agriculture, institutional, commercial	40%
Public	Park, Cemetery, Transportation	60%

Recommendation 2 – Maintain diversity in tree size

Overall, there appears to be the recommended distribution spread of tree sizes (based on figure 9a). However, over 64% of small stature trees are under 20cm, suggesting a young age. This suggests a young population of such trees, which will provide many more services in the coming decades as those trees grow.

It is not surprising that the larger trees were found in cemeteries and parks. Larger trees tend to occur where land use is unlikely to have changed in recent history, where a lack of disturbance can play an important role in these trees being able to grow to maturity. An interesting point is the proportion of large trees on institutional land. This suggests working with institutions such as schools and colleges will ensure the longevity of older trees.

Tree condition

The most frequent condition[11] of Southampton's trees is good and fair (both 36%). Unfortunately, poor is the third most common (16%), followed by excellent (9%) (Figure 10). Only 3% of trees were estimated as being dead, or "critical" and "dying" conditions*. Compared to other surveys, Southampton scored poorly; Inner London had 83% of their trees in an excellent or good condition, 90% excellent in Torbay, 66% good or excellent in Tawe catchment, and 71% trees in excellent condition in Edinburgh.

[11] Conditions: excellent = less than 1% dieback; good = 1-10% dieback; fair = 11-25%; poor to dead rating = 26-100% dieback (Nowak et al. 2008).

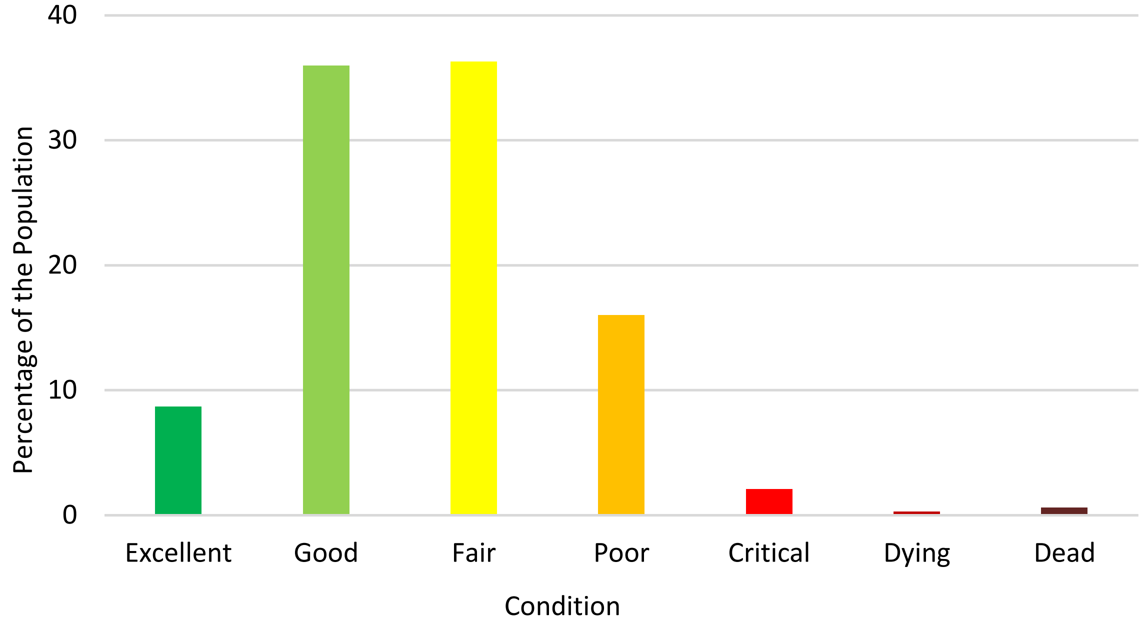


Figure 10. Percentage of the population by condition

Whitebeam, hazel and holly had the most trees in conditions of "poor" or poorer (Figure 11). This suggests that these species are somewhat susceptible to insect pests, disease and/or physical injury. The survey also shows the comparative good health exhibited by common lime, silver birch and sycamore.

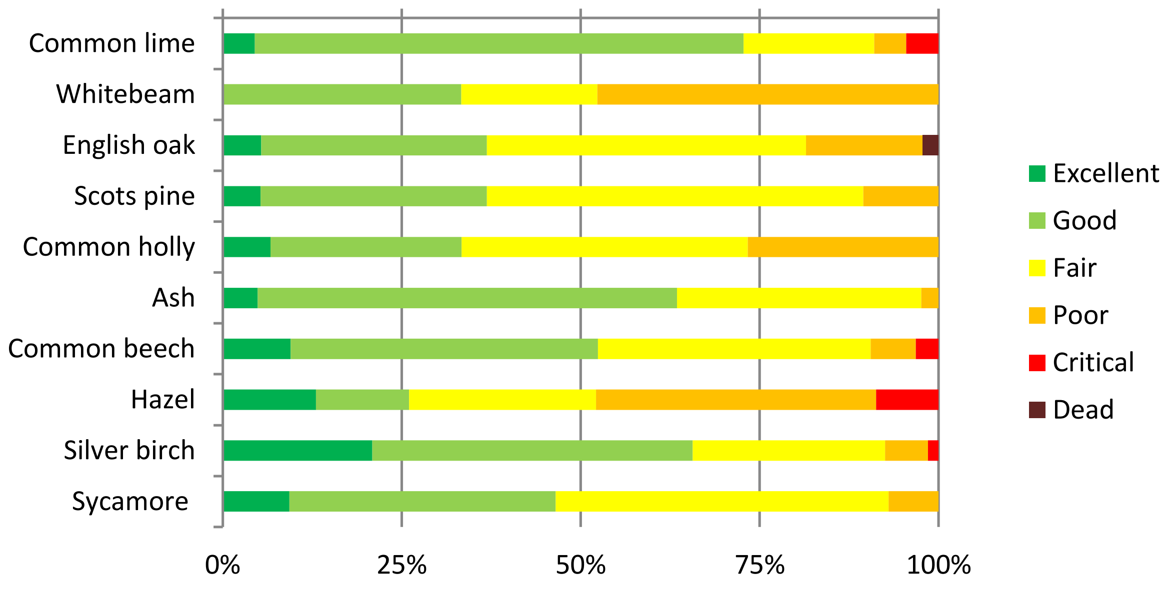


Figure 11. Tree condition by top 10 species (none of the top 10 species were in a dying condition)

Recommendation 3 – Undertake tree condition analysis

Southampton's tree condition is poorer than other cities where i-Tree Eco surveys have taken place. It is unclear why that should be the case, so further analysis of where the trees with the poorest conditions are could ensure targeted management and maintenance of those trees. In addition, the causes affecting the condition of the trees should be identified.

Leaf area and "dominance value"

The healthy leaf surface area of trees is an indicator of the extent to which trees can provide their benefits, including the removal of pollutants from the atmosphere (Nowak et al., 2006) and shade provision. The total leaf area provided by Southampton's trees is 109.5 km^2 – this is 2.2 times the survey area of Southampton. Sycamore has the largest percent leaf area (17.5%), followed by oak (14%) and beech (8.5%) (Figure 12).

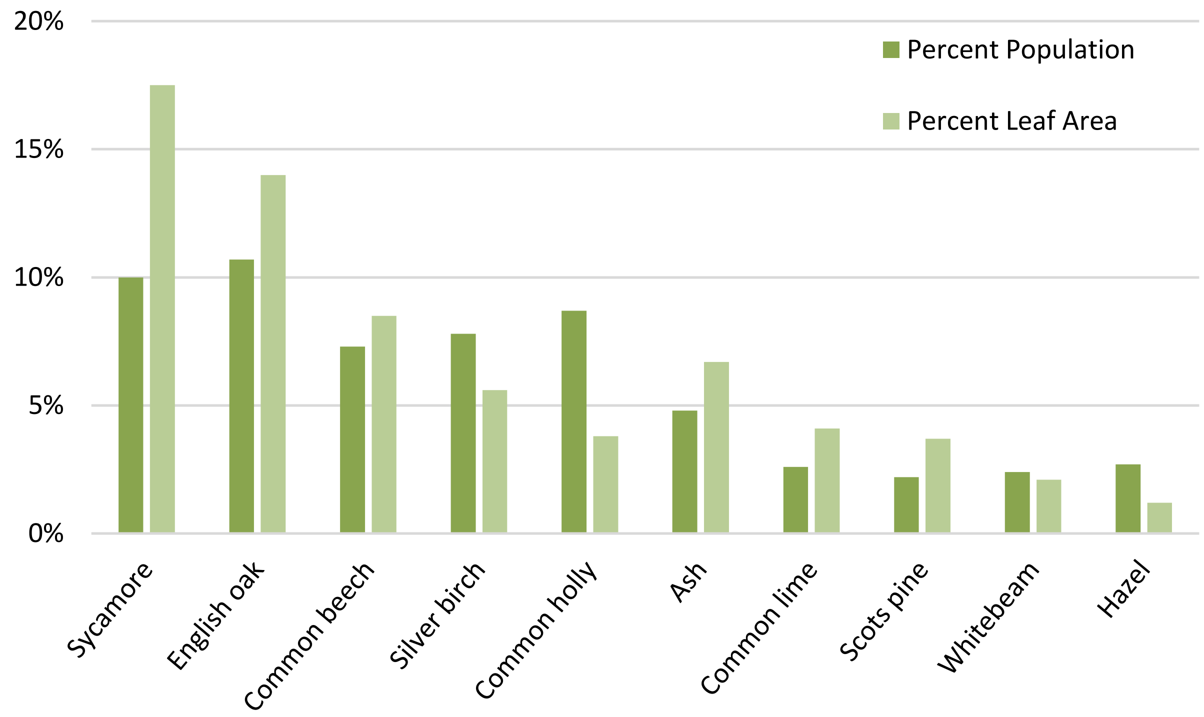


Figure 12. Population vs Leaf area of the trees recorded in the study

Dominance 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 forest are contributing most to ecosystem service provision. Thus, trees with dense canopies and/or large leaves tend to rank highly. The top tree species in the Southampton study, by dominance value, were those which appeared in greater numbers such as oak and sycamore, and those with large leaves, such as ash. A list of the dominance values for all species encountered during the study is presented in Appendix II - Species Dominance List.

Table 8. Dominance value of top ten species

Species	Dominance Value
Sycamore	27.5
English oak	24.7
Common beech	15.8
Silver birch	13.4
Common holly	12.5
Ash	11.5
Common lime	6.7
Scots pine	5.9
Whitebeam	4.6
Hazel	3.8

Recommendation 4 – Increase ecosystem service delivery

Maintaining a healthy population of trees is important for the current provision of ecosystem services to society. However, where large stature trees, such as oaks, limes and pines are currently found it will be important to make provision to retain these trees to maturation.

Large evergreen trees are important for year-round provision of ecosystem services. They are also considered important for achieving a high level of resilience in the long term and enhancing ecosystem service delivery via diversity of species and provision of a structurally diverse urban forest.

Birch, holly and ash are the species with the fourth, fifth and sixth highest dominance value in this study. Care of these, together with supplementary planting of more limes and evergreens such as Scots pine (also in the top ten in this study) would be an effective means to increase ecosystem service delivery across Southampton's urban forest.

Amenity value

Replacement cost is the cost of replacing the urban forest of Southampton should it be lost. In i-Tree Eco this is calculated using the CTLA (Council of Tree and Landscape Appraisers) method based on local nursery stock prices. The replacement cost of Southampton's trees was calculated as £282 million. The CTLA valuation method does not take into account the health or amenity value of trees, and is a management tool rather than a benefit valuation.

As such, a CAVAT (Capital Asset Value for Amenity Trees) valuation, which considers the health of trees and their public amenity value, was also undertaken. For the urban forest of Southampton, the **estimated total public amenity asset value is £3,215 million**. Oak had the highest overall value (Table 9, Figure 13), representing 20% of the total public amenity value of all the trees in Southampton's urban forest. The single most valuable tree encountered in the study was a common lime, estimated to have an asset value of £257,550.

Table 9. CAVAT values for the top ten trees by genus

Genus	Number of species	Estimated value of measured trees	Total value across Southampton (in millions)
Quercus	5	£2,160,000	655
Acer	6	£1,721,000	522
Pinus	1	£785,000	238
Fagus	1	£753,000	228
Tilia	4	£714,000	216
Fraxinus	1	£675,000	205
Betula	2	£522,000	158
Platanus	4	£360,000	109
Alnus	7	£266,000	81
Ilex	1	£226,000	69
Total	**32**	**£8,184,000**	**£2,480**

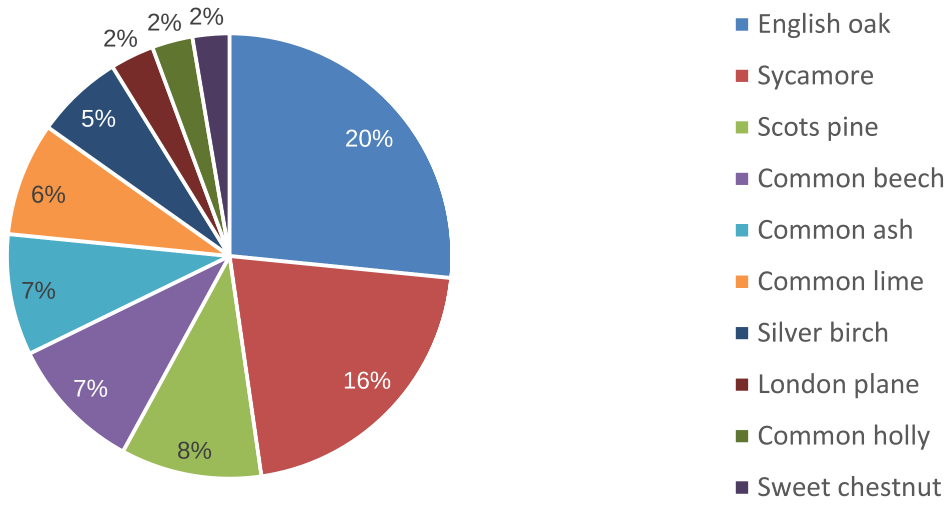


Figure 13. Ranking of top-ten tree species according to their CAVAT valuation

The land use type containing the highest CAVAT value of trees is ‘park’, with over a half of the total value of the trees and estimated value of approximately £5,190,762 (Figure 14). This equates to greater than £1,573 million when extrapolated for the whole of Southampton. 9% 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 risk 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.

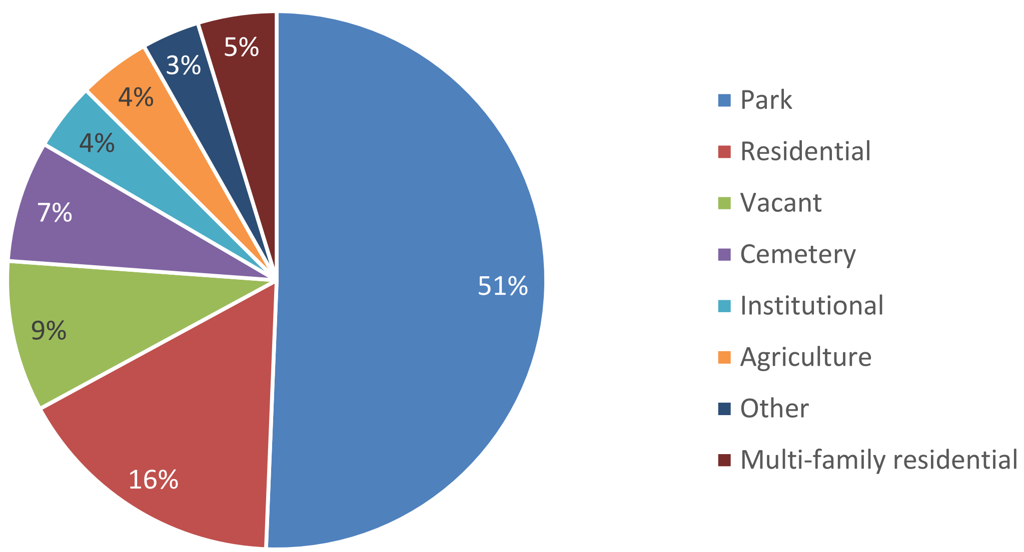
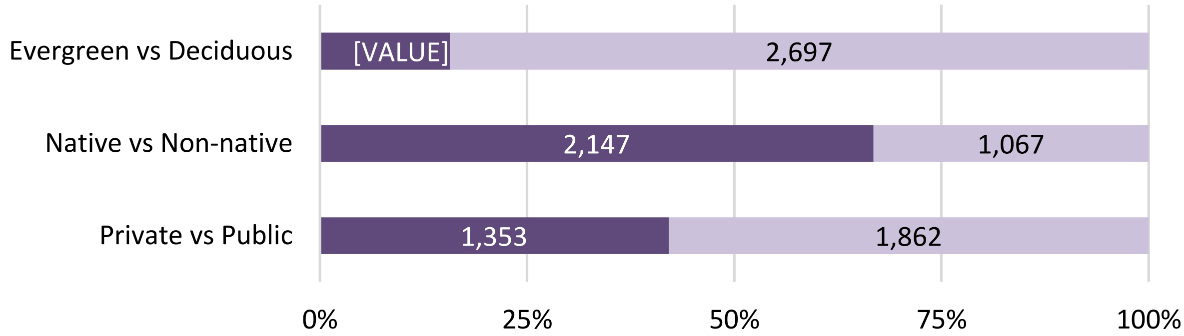


Figure 14. Percentage public amenity value according to land use type

The amenity value is higher in areas of public ownership, and for native and deciduous trees (Figure 15). However, non-native trees still contribute over a billion pounds of amenity value in Southampton.



Recommendation 5 – Conserve high value trees

Trees that have high CAVAT values are those of large size that are highly visible to the public, which are healthy and are well suited to the location, both in terms of their ability to grow there as well as their specific contribution to the character of the place.

Parks, residential and vacant were the land use types across Southampton with the greatest CAVAT value. These areas also contained the highest percentage of large stature trees. By conserving maturing large stature trees in publicly accessible places such as parks or in spaces where they can provide a sustainable urban drainage service (such as adjacent to wetland habitat, will help to ensure that the urban forest has high public amenity into the future. In addition, new developments should consider the existing trees on vacant sites and the benefits they are providing.

Preference should be given to large stature trees where possible, and to the selection of species with special amenity such as bark colour or canopy architecture. Selection should always be guided by local policy, diversity in planting for resilience, suitability to the soil type and it should be mindful of suitability to the location long term.

Figure 15. CAVAT values per annum by category (£ million)

Avoided surface water runoff

The infrastructure required to remove surface water in urban environments is costly and is outdated 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 storm water amelioration where the surface around the trees is permeable allowing the water to infiltrate into the soil. **The trees of Southampton intercept an estimated 94,894,990 litres of water per year**. Based on the Southern Water's 2016/17 household volumetric waste water rate[12], this saves just over £140,000 in avoided charges across Southampton annually (Table 10) or just over £3,065,000 if discounted over a 50-year period.

Table 10. Avoided runoff for trees in Southampton

Estimated number of trees	269,994
Leaf area	109.5 km^2
Avoided runoff	94,894,990 litres per year
Avoided runoff value	£143,894

Of individual tree species, sycamore intercepts the most water (16.6 million litres per year), worth some £25,100 in avoided sewerage charges (Figure 16). Deciduous and native trees intercept the most water (Figure 17).

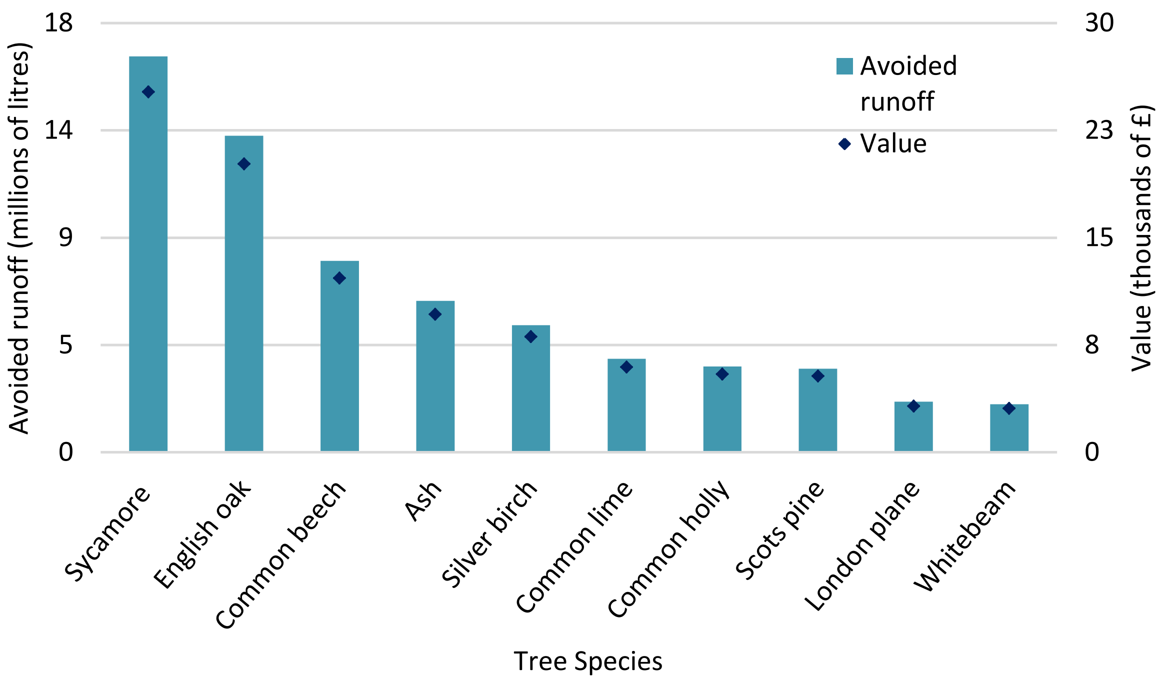


Figure 16. Individual species contribution to avoided runoff

[12] £1.310 per m^3 representing a metered water charge as there is no price for grey water only. Source: Southern Water, 2017

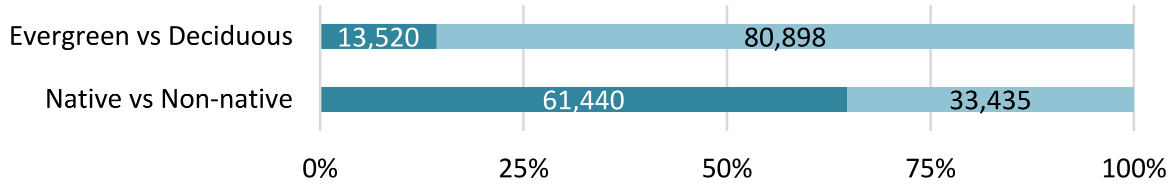


Figure 17. Difference between type and origin of tree species for amount of water intercepted. Values in m^3/yr

Recommendation 6 – Complement Sustainable Urban Drainage Systems

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 Southampton. Sycamore, oak and beech trees provide a valuable stormwater interception service, given their relative contributions to the total number of trees in the urban forest.

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.

Planting for interception should also be complemented with planning for Sustainable Urban Drainage Systems (SUDS). 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 (CIRIA, 2007). SUDS can actively incorporate trees in their design solution. 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. Trees can provide a positive contribution to a SUDS system. 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 quality is a key issue in Southampton, with the major sources of air pollution being road transport emissions (especially heavy goods vehicles) and industrial emissions associated with the port – the latter contributing up to 24% of the city's emissions (SCC, 2015a). Due to its excellent strategic position and channel characteristics, the city's port handles more vehicles than any other in the UK, is Europe's leading turnaround cruise port, and is the UK's most productive container port (ABP, no date). In addition to its port facilities, Southampton is served by a regional airport just outside the city's northern boundary, as well as the M3 and M27 Motorways. As such, Southampton has been identified as one of the few UK cities that will not meet the requirements of EU atmospheric pollution standards by 2020 (Li, 2016). Poor air quality can have multiple health effects (Table 11). Urban forests can counteract this.

It is estimated that Southampton's trees remove **90,000 kg** of airborne pollutants per year, including NO_2, O_3, SO_2, CO and $PM_{2.5}$. Ozone (O_3) and nitrogen dioxide (NO_2) were the pollutants removed in the highest quantities.

Table. 11 Types of pollutant, with health effects and their source. Source: www.air-quality.org.uk

Pollutant	**Health effects**	**Source**
Nitrogen dioxide (NO2)	Shortness of breath Chest pains	Fossil fuel combustion: predominantly power stations (21%), cars (44%) and ships
Ozone (O3)	Irritation to respiratory tract, particularly for asthma sufferers	From NO2 reacting with sunlight
Sulphur dioxide (SO2)	Impairs lung function Forms acid rain that acidifies freshwater and damages vegetation	Fossil fuel combustion: predominantly burning coal (50%) and fuel used in ships
Carbon monoxide (CO)	Long term exposure is life threatening due to its affinity with haemoglobin	Carbon combustion under low oxygen conditions (e.g. in petrol cars)
Small particulate matter (PM2.5)	Carcinogenic Responsible for tens of thousands of premature deaths each year	Various causes: cars (20%), ships and residential

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 (Figure 18, Table 12). This is because the value of some pollutants 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 includes $PM_{2.5}$, NO2 and SO2 pollutants, **£533,720** worth of pollutants are removed annually from the atmosphere (Table 11). Over a 50-year period, the capitalized (or net present) value of the combined removal of these three pollutants is **£16,904,670**.

Table 12. Results per pollutant

Pollutant	Mean amount removed (tonnes)	US value per tonne/$	Value ($: USEC)	UK value per tonne/£	Value (£: UKSDC)
CO	1.3	984	1,279	n/a	n/a
NO_2	26	6,835	177,710	12,205	317,530
O_3	55	6,930	381,150	n/a	n/a
$PM_{2.5}$	6.4	15,734	100,698	33,713	215,763
SO_2	2.2	913	2,009	1,656	4,303
TOTAL	**90.9**		**662,846**		**537,321**

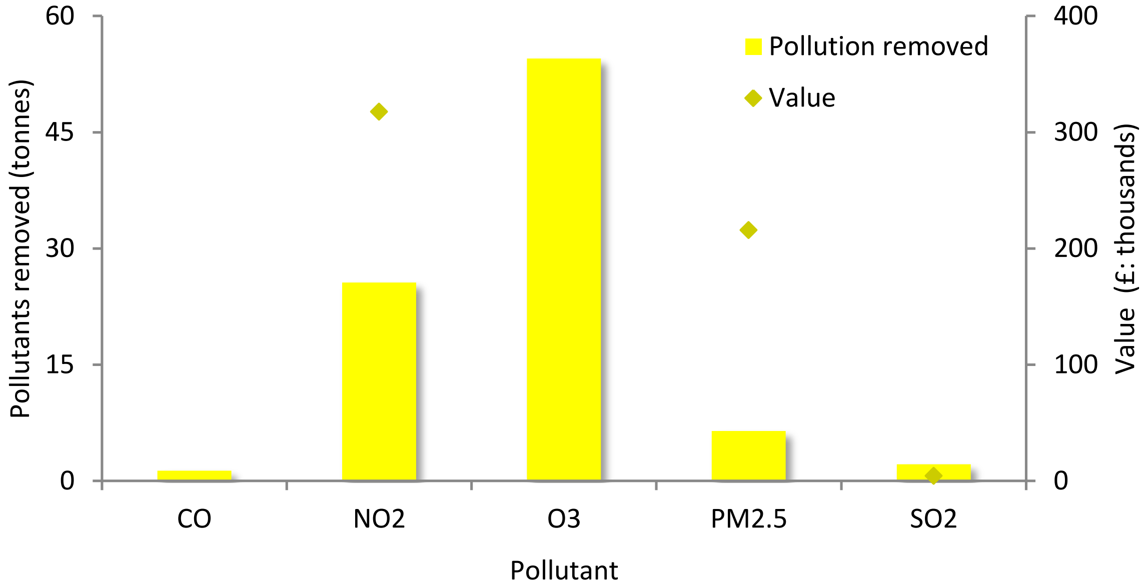


Figure 18. Mean quantity of pollutants removed (by pollutant) and the associated value (diamonds, valued using UKSDC).

The volume of airborne pollutants varied over the year, with a seasonal pattern evident in the removal of ozone, which was removed in higher volumes during spring and summer (Figure 19). This is because broadleaf species, which lose their leaves over the autumn and winter, are most effective at removing O3 (Alonso et al., 2011; Baró et al., 2014). Furthermore, ozone is a product of the combination of VOC's and NOx, which was also removed in greater volumes in summer due to the deciduous leaf-on period (Bowler et al., 2010)[13]. The production of ozone is also more prevalent in warm temperatures (Sillman & Samson 1995). This creates a diurnal pattern, with ozone levels higher during the day than at night (Nowak, 2000).

[13] In contrast, coniferous (evergreen) trees are better at accumulating airborne PM2.5 particles on their foliage than broadleaved species because of their thicker wax layer (Nguyen et al., 2015).

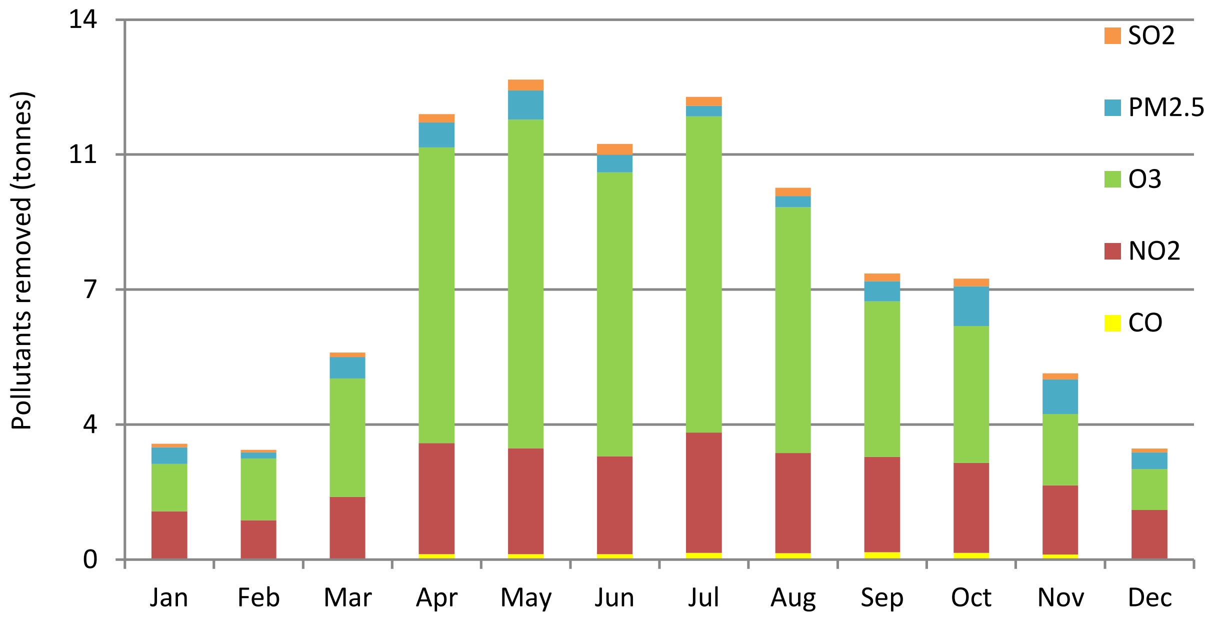


Figure 19. Pollutants removed on monthly basis

Carbon storage

Carbon storage:

All the carbon contained within trees (in their roots, main bole and branches)

Carbon sequestration:
Amount of carbon removed annually by trees. Across a city, net carbon sequestration can be negative if emission from decomposition is greater than that sequestered by growing trees.

Size matters:
Large trees are particularly important carbon stores and new plantings will help to ensure that current levels of forest cover is maintained or enhanced (McPherson, 1998).

It is estimated that Southampton's trees store a total of **100,583 tonnes** of carbon in their wood, with English oak storing the greatest amount (Figure 20). This is the equivalent to 12.6% of the total annual carbon emissions produced by all the households in Southampton[14, 15].

[14] 8.1 tonnes of CO_2e in 2014 per household (Committee on Climate Change, 2016)
[15] Estimated number of 98,300 households in Southampton from 2011 census (Southampton City Council, 2011)

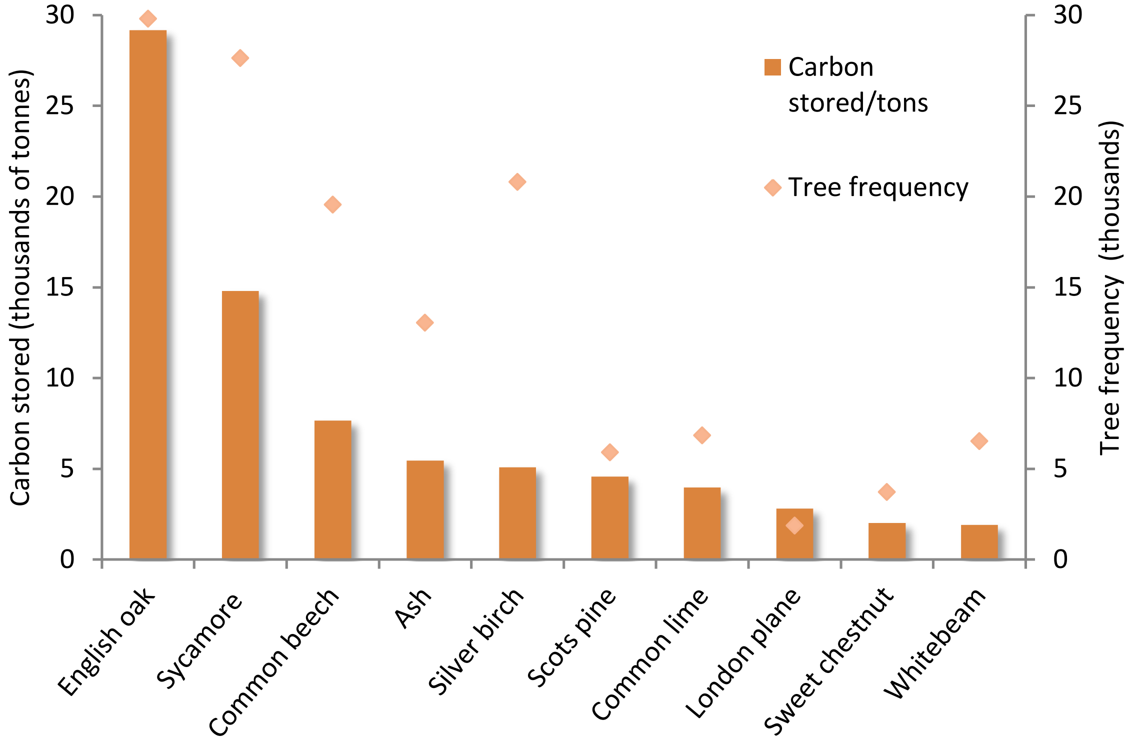


Figure 20. Carbon stored with frequency of each tree species (top 10)

Similarly to 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 11% of Southampton's tree population, but is responsible for storing 29% of the total carbon stored in trees; silver birch on the other hand, stores only 5.1% of carbon but makes up 8% of the tree population.

It is estimated that the carbon in the current tree stock is worth **£23.4 million**, based on the central scenario for non-traded carbon (DECC, 2015). In 2050, this stock of carbon will be worth £48.4 million – this value assumes no change in the structure of the forest in terms of species assemblage, tree size or tree population size, and simply reflects the increased valued of non-traded carbon year-on-year. Deciduous and native trees were found to store more carbon than evergreen and non-native trees respectively (Figure 21).

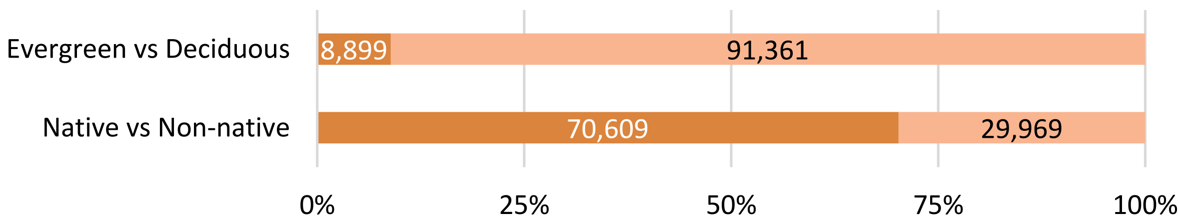


Figure 21. Carbon stored divided by category ([1]mt)

Carbon sequestration

The gross amount of carbon sequestered by trees in Southampton each year is estimated at **2,684 tonnes**. This amount of carbon is worth over **£609,327**. The annual net sequestration rate is equivalent to the annual emissions from 332 households (*CS above), or 0.3% of the total number of households in Southampton. Over 50 years, the net present value of carbon sequestration amounts to **£3,450,703**. Again, English oak sequesters the most carbon, followed by sycamore and beech (Figure 22). Deciduous and native trees once again sequester the most carbon (Figure 23).

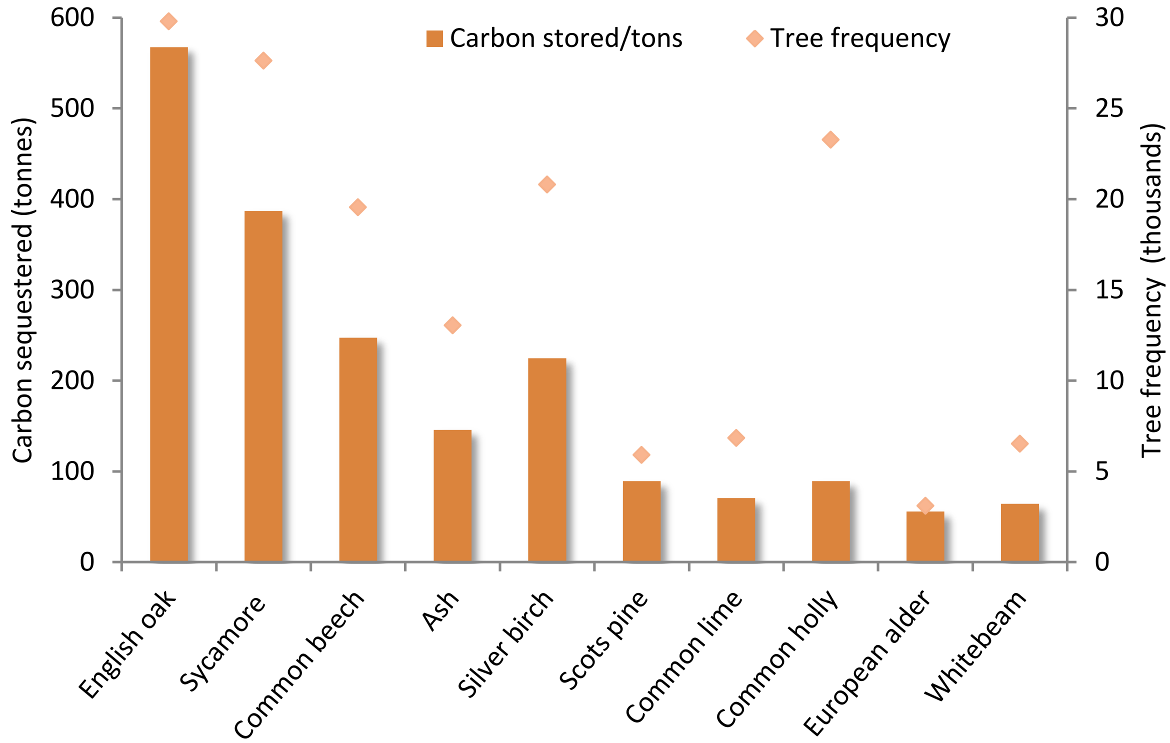


Figure 22. Carbon sequestered with frequency of each tree species

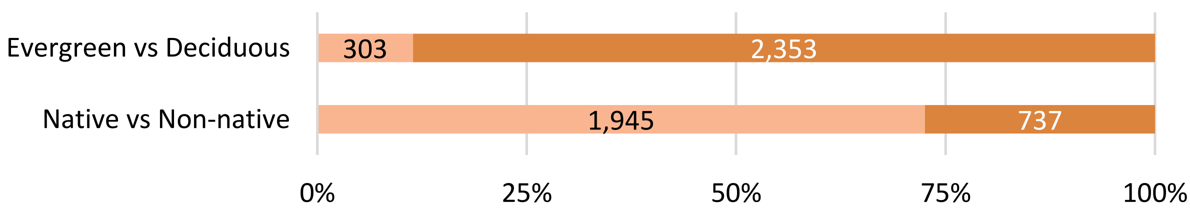


Figure 23. Carbon sequestered divided by category ([1]mt)

Recommendation 7 – Increase carbon storage and 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 reemitted 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 Southampton shows that there is an over reliance on oak: it holds over a quarter 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 (> 10 m height) upon maturity. It will also be important to choose species that will be tolerant of predicted climate change. Additionally, pioneer species, which tend to be quick growing, will have a positive impact on carbon storage in the short-term. Looking at http://www.righttrees4cc.org.uk/ can help to determine what species would be most suitable based on the above criteria.

IMD analysis

The index of multiple deprivation provides a relative ranking of areas across England according to their level of deprivation. It uses measures such as income, employment, crime and living environment (SCC, 2015b). Figure 24 shows the relative scores in Southampton.

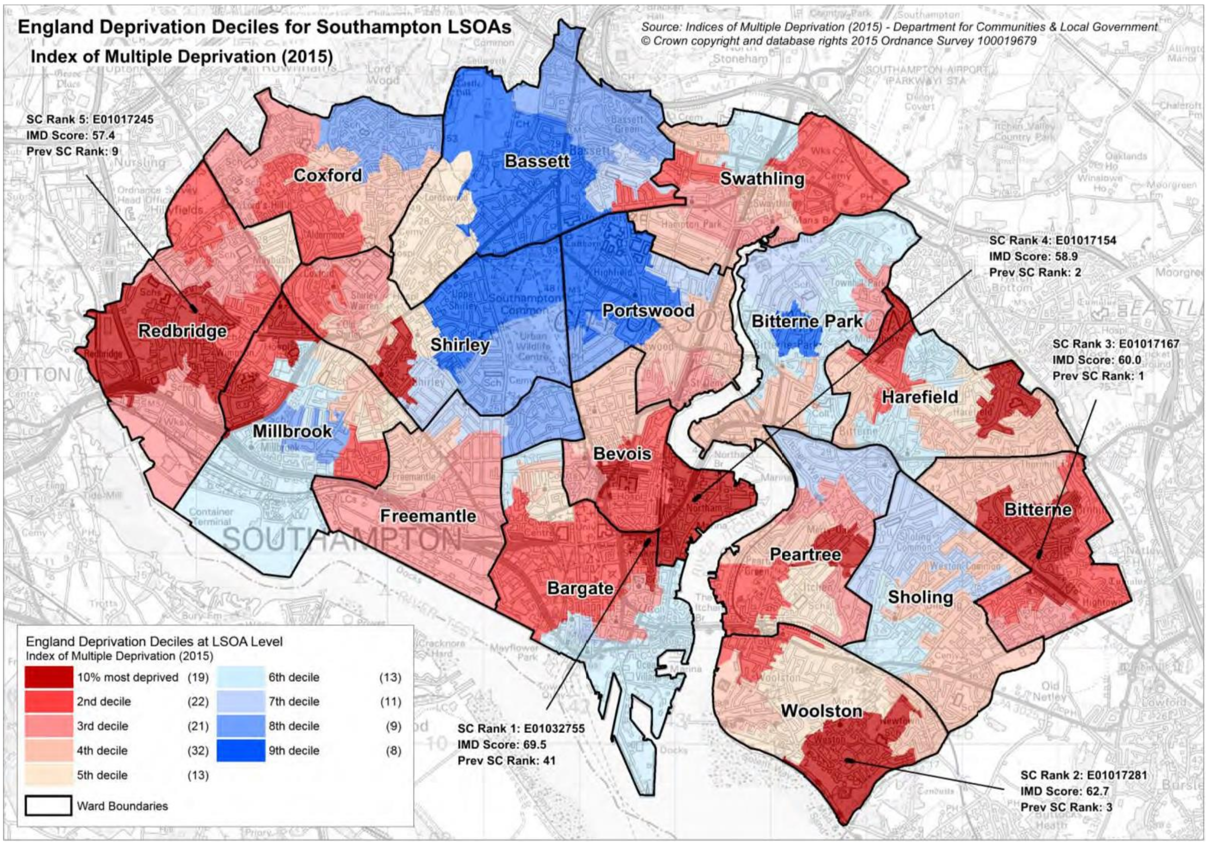


Figure 24. IMD values for Southampton (SCC 2015b)

There are known links between urban greenspace and deprivation, such as reducing mental fatigue of those who live in poverty when tackling major issues (Kuo, 2001) and increasing self-discipline of inner-city children (Taylor et al., 2002). This shows it can be important to know about the benefits provided by the urban forest in areas with different levels of deprivation. Before examining the results, it is important to know that the data from the i-Tree survey was post-stratified using the IMD data, which means there was not a proportional number of plots per IMD decile for Southampton. Thus, the following results provide an indication of the benefits provided by the urban forest in each category, but should not be used exclusively to describe the difference in benefits across IMD deciles.

Table 13 suggests the least deprived areas of Southampton (those in the 9th IMD decile) have the highest total value of amenity trees, whereas the most deprived areas (IMD 1) actually have the highest mean amenity value. The highest valued tree is found in the most deprived area. IMD’s 6, 7 and 8 have the lowest total value of amenity trees.

Table 13. CAVAT amenity value by IMD decile

IMD decile	Amenity value (sum of LSOAs[16] in each decile)	Amenity value (mean of LSOAs in each decile)
1	£1,076,000	£21,949 (this includes an individual tree with a value of £257,550. Excluding this tree gives a mean amenity value of £17,041)
2	£1,332,000	£14,320
3	£1,271,000	£10,084
4	£1,883,000	£12,551
5	£1,289,000	£17,661
6	£623,000	£16,388
7	£348,000	£9,410
8	£615,000	£9,927
9	£2,166,000	£9,803.

In contrast with this, Figure 25 shows that those living in the 4th and 9th IMD decile receive the most benefits, whilst those in the 7th decile receive the lowest. Surprisingly, the 1st and 2nd most deprived areas still receive a suitable proportion of the benefits, which suggests these areas have nearby access to the urban forest (though the data is skewed somewhat by the location of the largest and most valuable tree in an IMD 1 area). This contrasts with studies by Dobbs et al. (2014) and Li and Liu (2016) who find that abundance and accessibility of urban green space, and provision of ecosystem services, are negatively correlated with deprivation. Further analysis should be carried out to see if the difference between the urban forest benefits by IMD decile is significant.

[16] LSOAs are 'Lower Layer Super Output Areas', geographically defined by their population (between 1,000 and 3,000 people) and their number of households (between 400 and 1,200) (ONS, no date).

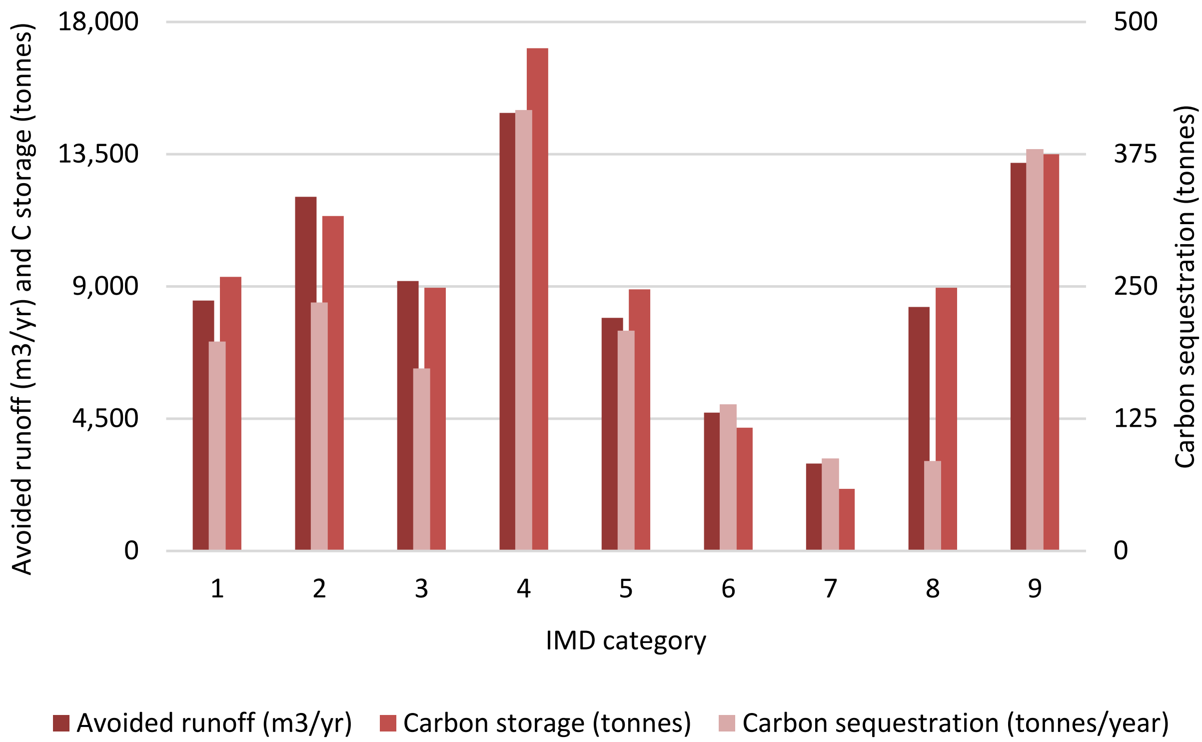


Figure 25. Benefit by IMD decile, where 1 is most deprived and 9 least deprived

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 (Vanbergen & The Insect Pollinators Initiative, 2013). Providing food sources could help. Southampton's trees and shrubs are contributing to this food source, with sixteen of the tree species found in the Southampton survey supporting pollinating insects (RHS, 2012) (Table 14).

Table 14. Trees encountered in Southampton that are beneficial to pollinators (adapted from RHS, 2012)

Species	Season
Apple	Spring
Hawthorn	Summer
Holly	Summer, Spring
Common lime	Summer

Common plum	Spring
Field maple	Spring
Goat willow	Spring
Bay laurel	Summer
Norway maple	Spring
Rowan	Summer
Small-leaved lime	Summer
Sweet cherry	Spring
Sycamore	Spring
Whitebeam	Summer

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 Southampton survey and for which insect data is available[17], willow and oaks support the most varied insect herbivore species (Table 15).

Non-native trees associate with fewer species than native trees as they have had less time to form associations with native organisms (Kennedy & Southwood, 1984). In addition, some native species form few insect herbivore associations due to their high level of defence mechanisms, yew being a good example (Daniewski et al., 1998). These species may support wildlife in other ways, for example by supplying structural habitat dead wood (buglife.org.uk, 2013).

Table 15. Numbers of insect species supported by tree species encountered in the Southampton 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. (-Non-native)*

Name	**E/D**	**Total**	**Beetles**	**Flies**	**True bugs**	**Wasps and sawflies**	**Moths and butterflies**	**Other**
Willows	D	450	64	34	56	104	162	9
Oak	D	423	67	7	81	70	189	9
Hawthorn	D	209	20	5	40	12	124	8

[17] Insect data is not available for all species encountered in Southampton; only species studied in Southwood (1961) and Kennedy and Southwood (1984) are included. Even closely related species such as apples and pears are not included as data was not available for the domesticated species.

Scots pine*	E	172	87	2	25	11	41	6
Alder	D	141	16	3	32	21	60	9
Crabapple	D	118	9	4	12	2	71	2
Hazel	D	106	18	7	19	8	48	6
Beech	D	98	34	6	11	2	41	4
Norway spruce	E	70	11	3	14	10	22	1
Ash	D	68	1	9	7	7	25	9
Rowan	D	58	8	3	6	6	33	2
Field maple	D	51	2	5	10	2	24	6
Hornbeam	D	51	5	3	10	2	28	2
Sycamore*	D	43	2	3	11	2	20	5
Common juniper	E	32	2	5	1	1	15	2
Sweet chestnut*	D	11	1	0	1	0	9	0
Holly	E	10	4	1	2	0	3	0
Horse chestnut*	D	9	0	0	5	0	2	2
English walnut*	D	7	0	0	2	0	2	3
English yew	E	6	0	1	1	0	3	1
Holly oak*	E	5	0	0	1	0	4	0
Black locust*	D	2	0	0	1	1	0	0

Recommendation 8 – Encourage planting

Trees and shrubs provide valuable habitat and food for many animal and plant species. Data availability on the role that each tree and shrub species has in supporting biodiversity found in the urban environment is far from comprehensive. However, over-arching principles such as native trees and shrubs association with more faunal species than non-natives, can be used to plan for an urban forest that complements local biodiversity.

Similarly, preferential planting of species identified in Tables 14 and 15 could be encouraged amongst private as well as public land owners. For example, local residents can be encouraged to play their part through education and awareness raising publications by the RHS, RSPB and others on gardening for wildlife.

Recent research has shown that exotic plants can extend the flowering season and provide additional resources to pollinators when the abundance of flowers on native and near-native plants was low. In addition, interactions between an exotic plant and some pollinators suggest that exotic plant species can be especially valuable to some insect species. Therefore, selecting trees from one region of origin may not be the optimal strategy for providing resources for pollinating insects in urban landscapes. It seems that the best advice is to encourage the planting of a variety of trees in Southampton biased towards native and near-native species with a careful selection of exotics to extend flowering season and hence food provision for some groups, for example solitary bees (Salisbury et al. 2015).

Risks of pests and disease

Pests and diseases are a serious threat to urban forests. Severe outbreaks have occurred within living memory, with Dutch elm disease killing approximately 30 million trees in the UK (Webber, 2010). Climate change may exacerbate this problem, ameliorating the climate for some pests and diseases, making outbreaks more likely (Forestry Commission, 2014). Assessing the risk pests and diseases pose to urban forests is, therefore, of paramount importance to their long-term security and management. 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 Southampton on a single genus (Table 16) and for multiple genera (Table 17).

Table 16. Risk matrix used for the probability of a pest or disease becoming prevalent in the Southampton urban forest on a single genus (one or more species).

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

Table 17. Risk matrix used for the probability of a pest or disease becoming prevalent in the Southampton urban forest on multiple genera.

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

With increased importation of wood and trees in addition to a climate that is becoming more conducive to many pests and diseases, ensuring urban forests are resilient is of paramount importance. Protecting the urban forest as a whole against threats can be helped by increasing the diversity of tree species across Southampton.

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 (Forestry Commission, 2014). 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; for example, Observatree (www.observatree.org.uk) and Treezilla (www.treezilla.org).

Table 18 gives an overview of the current and emerging pest and diseases that could affect Southampton's urban forest, 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 VI – Pests and diseases**. The tables present the population of the urban forest of Southampton at risk from each pest and disease, the associated amenity value of these trees and the value of the carbon that they store. Subsequently, the tables highlight the relative impact of these pests and diseases and indicate the likely impact on canopy coverage and diversity of the urban forest should the pest or disease become established.

It should be noted that most of the threats identified in Table 18 are particularly relevant to oak and ash, two of the most common species amounting to around 15% of the city's tree stock, and contributing proportionally more to many ecosystem services. 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.

Recommendation 9 – Consider pests and diseases

Ash dieback has raised serious concerns about the health of our trees. A combination of climate change and the accidental and deliberate introduction of non-native species pose a threat through increased incidence of pests and diseases. By increasing the importance of managing the existing tree stock and planting new trees, this will increase the resilience woodland and greenspaces. Local Authorities should review their tree inventory to identify where these may be under threat now or in 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 a changing climate. See: www.righttrees4cc.org.uk

Table 18. Risks of emerging pests and diseases

Pest/ Pathogen	Species affected	Prevalence in the UK	Prevalence in South East	Risk of spreading to South East	Population at risk (%)	CAVAT value of sampled trees (£)
Acute oak decline	*Quercus robur, Q. petraea*	SE England , the Midlands, East Anglia and Wales	Confirmed cases	High - already present	**11.1%**	2,107,626
Asian longhorn beetle	Many broadleaf species (see Appendix IV)	None (previous outbreaks contained)	None	Medium risk – climate may be suitable	**51.3%**	5,394,856
Chalara dieback of ash	*Fraxinus excelsior, F. angustifolia*	Cases across the UK	Confirmed cases in Southampton	High - already present	**4.8%**	674,9367
Emerald ash borer	*F. excelsior, F. angustifolia*	None	None	Medium risk (imported wood)	**4.8%**	674,9367
Giant polypore	Primarily *Quercus* spp., *Fagus* spp., *Aesculus* spp., *Sorbus* spp. and *Prunus* spp	Common in urban areas	Common in urban areas	High – already present	**26.1%**	3,332,416

Pest/ Pathogen	Species affected	Prevalence in the UK	Prevalence in South East	Risk of spreading to South East	Population at risk (%)	CAVAT value of sampled trees (£)
Gypsy Moth	Primarily *Quercus sp.*, secondarily *Carpinus betulus*, *F. sylvatica*, *C. sativa*, *B. pendula* and *Populus sp.*	London, Aylesbury and Dorset	None	Medium risk – slow spreading	**31.3%**	3,906,133
Oak processionary moth	*Quercus* spp.	London and Southern England	Confirmed cases	High - already present	**11.4%**	2,160,415
Oak processionary moth	*Quercus* spp.	London and Southern England	Confirmed cases	High - already present	**11.4%**	2,160,415
Phytophthora ramorum	*Q. cerris, Q. rubra, Q. ilex, F. sylvatica, C. sativa, Larix decidua, L. x eurolepsis*	Many UK sites, particularly in S Wales and SW England	Present – Official action guidelines give the area a medium risk	Medium	**8.7%**	1,067,705
Phytophthora kernoviae	*F. sylvatica, Ilex aquifolium, Q. robur, Q. ilex*‡	Mainly SW England and Wales	None	Medium – present in the South West	**26.7%**	3,087,199
Phytophthora alni	*Alnus* spp.	Riparian ecosystems in the UK	Highest incidence rate in South East	High – already present	**1.6%**	266,465
Dothistroma (red band) needle blight	*Pinus nigra ssp. laricio, P. contorta var. latifolia, Pinus sylvestris*	Several UK sites	Present in the South East	High – already present	**2.2%**	784,902
Spruce bark beetle	*Picea* spp.	Mainly W England and Wales	None	Medium – present in West England	**0.4%**	25,299

Conclusions

i-Tree Eco has provided the means to examine the trees in Southampton in a comprehensive manner. Its results and findings complement those studies mentioned in the introduction.

Main findings

Like many other British towns, cities and other urban centres, Southampton 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. For example, the city's population is one of the fastest growing in Europe (Eurostat, 2016), and its limited land area means that population density is already amongst the highest in the UK (exceeded only by London and Portsmouth). 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 stock take, not just of the trees themselves, but of what they deliver for us.

Southampton is estimated to contain around 267,000 trees, with 52 trees per ha. Large diameter trees accounted for over 10% of the trees surveyed with cemeteries, institutional land and parks containing the highest proportion of large trees; residential and vacant land were the next most important reserves of large trees. A further 14% of trees surveyed were medium sized with a 40-60 cm diameter, suggesting that the proportion of large trees believed to be indicative of a resilient forest can be reached in the short term with prudent protection and management.

The ecosystem services provided by trees are on-going and could become more valuable in the future as external factors change. For example, there is an increasingly urgent need to reduce levels of atmospheric carbon in order to mitigate climate change, whilst the already changing climate is leading to more frequent and severe (surface-water) flooding in many UK cities (Committee on Climate Change, 2017). In Southampton, poor air quality associated with a congested road network and the port is an increasing problem, resulting in the recent designation of a 'Clean Air Zone' in the city (Defra, 2015). Planning tree stocks to maintain a high level of ecosystem service delivery is, therefore, of paramount importance (Davies et al., 2017a,b).

A total of 103 tree species were identified in the survey. Species diversity was higher than the average compared with other i-Tree Eco surveys (though lower than central London), which is necessary for ensuring resilience of urban trees against pests and diseases. The twelve most abundant tree species in Southampton accounted for 68.2% of the population, and the proportions of the two most common species (oak and sycamore) exceeded the recommended limit of 10% abundance for any one single species. This implies that new strategic planning for the urban forest of Southampton is required to make it more diverse and resilient to future changes.

Diversity was highest on residential land, parkland and institutional land. Southampton could improve the diversity of the urban forest by targeting areas with lower diversity. Many of these, such as vacant land, can be influenced by local policy and devices such as the Green Space Factor in planning decisions. Native and deciduous trees were found to be most prevalent, as well as providing greater benefits compared with non-native and evergreen species. Despite this, a few non-native species are important for habitat provision and improve urban resistance to native pests and diseases, whilst evergreen species are particularly effective at removing $PM_{2.5}$, and reducing surface water runoff in winter during the deciduous leaf-off period.

The highest amenity values in Southampton were given to trees in parks, emphasising the importance of this land use as a benefit to local residents. Highlighting the amenity value of trees within these areas could enable the local council to demonstrate their value to potential novel funders, such as sponsorship campaigns.

There is a greater proportion of larger trees in public ownership compared with private ownership. Larger trees (and larger canopied trees) are known to provide greater benefits than small trees, particularly regarding carbon storage and sequestration, air pollution removal, avoided surface water runoff, habitat provision, recreation potential and aesthetics (Davies et al., 2017a). Larger trees on public land suggests that more people will be able to benefit from the ecosystem services they provide than if they were on private land, however the quantity, quality and accessibility of public green spaces (including trees) tends to be lower in deprived areas (Kabisch & van den Bosch, 2017).

The net carbon sequestered annually by Southampton's trees was 2,684 tonnes. This information and the other values for the benefits of trees highlighted in this report can be used to shape policy or local targets for protecting existing trees and encouraging the expansion of the urban forest. The annual carbon sequestration by trees can be compared to carbon emitting practices, such as annual emissions by homes within Southampton, and could then be used to inform tree planting to offset a proportion of the CO_2 emissions. In this way, tangible goals can be incorporated into local policy.

The IMD analysis has shown there appeared to be equal benefits from the urban forest between the least and most deprived areas. However, the 6^{th}, 7^{th} and 8^{th} decile were lower than expected, which could be linked to study design. Further research needs to be undertaken in this area before drawing conclusions.

Recommendations

The recommendations of the report are as follows:

1. Increase species diversity
2. Maintain diversity in tree size
3. Undertake tree condition analysis
4. Increase ecosystem service delivery
5. Conserve high value trees
6. Complement Sustainable Urban Drainage Systems

7. Increase carbon storage and sequestration
8. Encourage planting
9. Consider pests and diseases

Southampton City Council aim to increase canopy cover by 6.5% to **25% canopy cover**[18]. This could be achieved through street planting or mandatory planting of trees on new developments in Southampton. A successful initiative which could act as a template is the Mersey Forest (http://www.merseyforest.org.uk/). This initiative has an active programme of tree planting across a wide area through working with a range of partners and the community, as well as strategic funding.

As has been highlighted throughout the report, urban trees in Southampton provide several benefits to all those who live there. As such, the urban forest should be valued, just like other beneficial infrastructure projects (e.g. drainage and energy infrastructure). Planning and policy should reflect this, valuing trees as an essential component of urban life.

Limitations

i-Tree Eco does have limitations. Not all benefits provided by trees are quantified, including the calming effect that trees have on noise pollution and their ability to cool the urban environment. Nor is it possible to explore the value of Southampton's trees for attracting visitors and shoppers, for supporting health and well-being, or for enhancing property values using the i-Tree survey approach. The value of these additional 'services' could be very large too. The urban forest in Southampton is therefore more valuable than stated in this report. Future developments in i-Tree Eco may enable these extra benefits to supplement this report in the future, giving a more comprehensive picture. Alternatively, additional independent assessments can be used to complement the i-Tree Eco values, as performed herein with CAVAT.

This study is also limited given that it is a snapshot of the urban forest. Monitoring, using the same or a comparable technique, will allow variations to be taken into account and in the long term could be used to illustrate dynamic processes such as climate change and allow a robust long-term picture to be built. It is recommended that an i-Tree Eco survey is conducted every 5-7 years to support the management and planning of Southampton's urban forest.

[18] This new tree canopy target will be published in the forthcoming Air Quality Management Plan, and in the forthcoming revision to Southampton's Tree Operational Risk Management System (STORMS) policy document.

The authors

Emma Mutch, Helen Davies, Malcolm Hudson, Kate Parks and Kate Schreckenberg
Centre for Environmental Science
Faculty of Engineering and the Environment
University of Southampton
Southampton
SO17 1BJ

Kieron Doick and Phil Handley
Urban Forest Research Group
Centre for Sustainable Forestry and Climate Change
Forest Research
Alice Holt
Surrey
GU10 4LH

Kenton Rogers
Treeconomics Ltd
Innovations Centre
University of Exeter
Devon
EX4 4RN

Sarah Kiss and Lindsay McCulloch
Southampton City Council
Civic Centre
Southampton
SO14 7LY

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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; PM2.5);
- 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 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,
Water/wetland	Streams, rivers, lakes, and other water bodies (natural or manmade). 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.

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 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, based on charges levied by Scottish Water. For Southampton, £1.310 per m^3 represented a metered water charge (Southern Water, 2017).

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 (Nowak, 1994). 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 (Baldocchi, 1988; Baldocchi et al., 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser, 1972; Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal assumes a 50% resuspension rate of particles (Zinke, 1967).

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 (Nowak et al., 2002), 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, 2015).

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).

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 Southampton survey 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 cm2 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 Southampton

area at 150%. 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-nationalcommunity-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).

Table A2. Life expectancy conversion factors

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 dominance list

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

Table A3. Dominance values

Rank	Species	Dominance Value	Percent Leaf Area	Percent Population
1	Sycamore	27.5	17.5	10
2	Oak	24.7	14	10.7
3	Beech	15.8	8.5	7.3
4	Silver birch	13.4	5.6	7.8
5	Holly	12.5	3.8	8.7
6	Ash	11.5	6.7	4.8
7	Common lime	6.7	4.1	2.6
8	Scots pine	5.9	3.7	2.2
9	Whitebeam	4.6	2.1	2.4
10	Hazel	3.8	1.2	2.7
11	Hawthorn	3.7	1.1	2.7
12	Bay laurel	3.6	0.8	2.8
13	Leyland cypress	3	0.7	2.3
14	Western redcedar	3	1.2	1.7
15	London plane	2.9	2.2	0.7
16	Alder	2.6	1.5	1.2
17	Common apple	2.5	1	1.5
18	Sweet chestnut	2.5	1.1	1.4
19	Hornbeam	2.5	0.8	1.6
20	Horse chestnut	2.2	1.4	0.8
21	Sweet cherry	2.2	0.9	1.3
22	Goat willow	2.2	1.2	1

23	Common privet	2	0.6	1.4
24	Common plum	1.6	0.2	1.4
25	Aspen	1.5	0.3	1.3
26	Yew	1.5	0.9	0.6
27	Smoothleaf elm	1.5	0.9	0.6
28	Downy birch	1.4	0.2	1.2
29	Grey poplar	1.2	1	0.2
30	Giant dracaena	1.2	0.2	0.9
31	Field maple	1.2	0.5	0.7
32	Sessile oak	1.1	0.8	0.3
33	Grey alder	1.1	0.8	0.3
34	Lawson cypress	1.1	0.5	0.6
35	Norway maple	1	0.8	0.2
36	Black poplar	1	0.7	0.3
37	Rowan	1	0.4	0.6
38	Black locust	0.9	0.7	0.2
39	American sycamore	0.9	0.7	0.2
40	Bird cherry	0.8	0.4	0.3
41	Elder	0.7	0.1	0.6
42	Bald cypress spp	0.7	0.4	0.2
43	Rhododendron spp	0.6	0.1	0.5
44	Oriental planetree	0.6	0.5	0.1
45	Serviceberry spp	0.6	0.2	0.3
46	Willow spp	0.6	0.2	0.3
47	Crabapple	0.5	0.2	0.3
48	Red elderberry	0.5	0.4	0.1
49	Large-leaved lime	0.5	0.4	0.1
50	Magnolia spp	0.5	0.3	0.2
51	Red silky oak	0.5	0.4	0.1
52	Sitka spruce	0.5	0.4	0.1

53	Crimean linden	0.5	0.4	0.1
54	Sargent's rowan	0.5	0.1	0.3
55	Small-leaved lime	0.5	0.4	0.1
56	Turkey oak	0.5	0.1	0.2
57	English walnut	0.4	0.3	0.1
58	Common pear	0.4	0.2	0.2
59	Elm	0.4	0.2	0.2
60	Common prickly ash	0.4	0.2	0.2
61	Common lilac	0.4	0	0.3
62	Holly oak	0.4	0.3	0.1
63	Monterey cypress	0.4	0.3	0.1
64	Portugal laurel	0.4	0.1	0.2
65	Norway spruce	0.3	0.1	0.2
66	Red alder	0.3	0.2	0.1
67	Spinning gum	0.3	0.2	0.1
68	Arizona cypress	0.3	0.2	0.1
69	Nordmann fir	0.3	0.2	0.1
70	Larch spp	0.3	0.1	0.1
71	Cyprus plane	0.3	0.1	0.1
72	Cherry plum	0.3	0	0.2
73	Bhutan cypress	0.2	0	0.2
74	Kwanzan cherry	0.2	0.1	0.1
75	Cockspur hawthorn	0.2	0.1	0.1
76	Cappadocian maple	0.2	0.1	0.1
77	Staghorn sumac	0.2	0.1	0.1
78	Variegated pittosporum	0.2	0.1	0.1
79	Sweetbay	0.2	0.1	0.1
80	Japanese maple	0.2	0.1	0.1
81	Mahonia spp	0.2	0.1	0.1

82	Hebe spp	0.2	0	0.1
83	Callery pear Chanticleer	0.2	0	0.1
84	Blackbutt	0.2	0	0.1
85	Silver maple	0.2	0	0.1
86	Common fig	0.1	0	0.1
87	Cedar	0.1	0	0.1
88	Fig spp	0.1	0	0.1
89	Chinese plum yew	0.1	0	0.1
90	Laurustinus	0.1	0	0.1
91	Tamarisk spp	0.1	0	0.1
92	Azalea	0.1	0	0.1
93	Fan palm spp	0.1	0	0.1
94	Mountain white gum	0.1	0	0.1
95	Date palm	0.1	0	0.1
96	palm(brahea) spp	0.1	0	0.1
97	Monkeypuzzle tree	0.1	0	0.1
98	Dutch elm	0.1	0	0.1
99	Royal paulownia	0.1	0	0.1
100	Bloodtwig dogwood	0.1	0	0.1
101	Olive	0.1	0	0.1
102	Juniper	0.1	0	0.1
103	California laurel	0.1	0	0.1

Appendix III. Non-traded values for carbon stored in Southampton'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.

Table A4. Carbon values

					Non-traded unit value (£/tCO2e)			Value of discounted stored tCO2e
	Year	Stored C (t)	Net sequestered C (t)	Stored C (tCO2e)	Central	Discount rate	Discount factor	Central
	2016	100,583	2,684	368,804	63	3.5	1.00	23,365,950
1	2017	103,267	2,684	378,646	64	3.5	0.97	23,497,133
2	2018	105,951	2,684	388,489	65	3.5	0.93	23,613,087
3	2019	108,636	2,684	398,331	66	3.5	0.90	23,714,383
4	2020	111,320	2,684	408,173	67	3.5	0.87	23,801,573
5	2021	114,004	2,684	418,015	68	3.5	0.84	23,914,397
6	2022	116,688	2,684	427,858	69	3.5	0.81	24,007,982
7	2023	119,373	2,684	437,700	71	3.5	0.78	24,082,913
8	2024	122,057	2,684	447,542	72	3.5	0.75	24,139,779
9	2025	124,741	2,684	457,385	73	3.5	0.73	24,179,172
10	2026	127,426	2,684	467,227	74	3.5	0.70	24,201,685
11	2027	130,110	2,684	477,069	75	3.5	0.68	24,207,911
12	2028	132,794	2,684	486,911	76	3.5	0.65	24,198,440

13	2029	135,478	2,684	496,754	77	3.5	0.63	24,173,861
14	2030	138,163	2,684	506,596	78	3.5	0.61	24,134,756
15	2031	140,847	2,684	516,438	86	3.5	0.59	25,947,188
16	2032	143,531	2,684	526,281	93	3.5	0.57	27,684,276
17	2033	146,215	2,684	536,123	100	3.5	0.55	29,346,237
18	2034	148,900	2,684	545,965	108	3.5	0.53	30,933,461
19	2035	151,584	2,684	555,807	115	3.5	0.51	32,446,503
20	2036	154,268	2,684	565,650	122	3.5	0.49	33,886,059
21	2037	156,952	2,684	575,492	129	3.5	0.47	35,252,960
22	2038	159,637	2,684	585,334	137	3.5	0.46	36,548,151
23	2039	162,321	2,684	595,177	144	3.5	0.44	37,772,688
24	2040	165,005	2,684	605,019	151	3.5	0.43	38,927,716
25	2041	167,689	2,684	614,861	159	3.5	0.41	40,014,468
26	2042	170,374	2,684	624,703	166	3.5	0.40	41,034,248
27	2043	173,058	2,684	634,546	173	3.5	0.38	41,988,425
28	2044	175,742	2,684	644,388	180	3.5	0.37	42,878,425
29	2045	178,426	2,684	654,230	188	3.0	0.36	43,932,174
30	2046	181,111	2,684	664,073	195	3.0	0.35	44,933,863
31	2047	183,795	2,684	673,915	202	3.0	0.34	45,884,176

32	2048	186,479	2,684	683,757	210	3.0	0.33	46,783,846
33	2049	189,164	2,684	693,600	217	3.0	0.32	47,633,651
34	2050	191,848	2,684	703,442	224	3.0	0.31	48,434,411
35	2052	194,532	2,684	713,284	232	3.0	0.30	49,323,419
36	2053	197,216	2,684	723,126	240	3.0	0.29	50,108,822
37	2054	199,901	2,684	732,969	247	3.0	0.28	50,852,764
38	2055	202,585	2,684	742,811	255	3.0	0.27	51,548,823
39	2056	205,269	2,684	752,653	263	3.0	0.26	52,148,582
40	2057	207,953	2,684	762,496	270	3.0	0.26	52,712,253
41	2058	210,638	2,684	772,338	277	3.0	0.25	53,179,445
42	2059	213,322	2,684	782,180	284	3.0	0.24	53,573,050
43	2060	216,006	2,684	792,022	291	3.0	0.23	53,905,738
44	2061	218,690	2,684	801,865	298	3.0	0.23	54,169,495
45	2062	221,375	2,684	811,707	304	3.0	0.22	54,148,825
46	2063	224,059	2,684	821,549	309	3.0	0.21	54,097,525
47	2064	226,743	2,684	831,392	314	3.0	0.21	53,929,224
48	2065	229,427	2,684	841,234	318	3.0	0.20	53,697,822
49	2066	232,112	2,684	851,076	322	3.0	0.19	53,358,458
50	2067	234,796	2,684	860,918	326	3.0	0.19	52,956,894

Appendix IV. Pests and diseases

Acute Oak Decline

Acute oak decline (AOD) affects mature 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 incidence of AOD in Britain is un-quantified at this stage but estimates put the figure at a few thousand affected trees. The condition seems to be most prevalent in the Midlands and the South East of England as far west as Wales. The disease poses a high risk to Southampton.

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 high felling, sanitation and quarantine are the only viable management options.

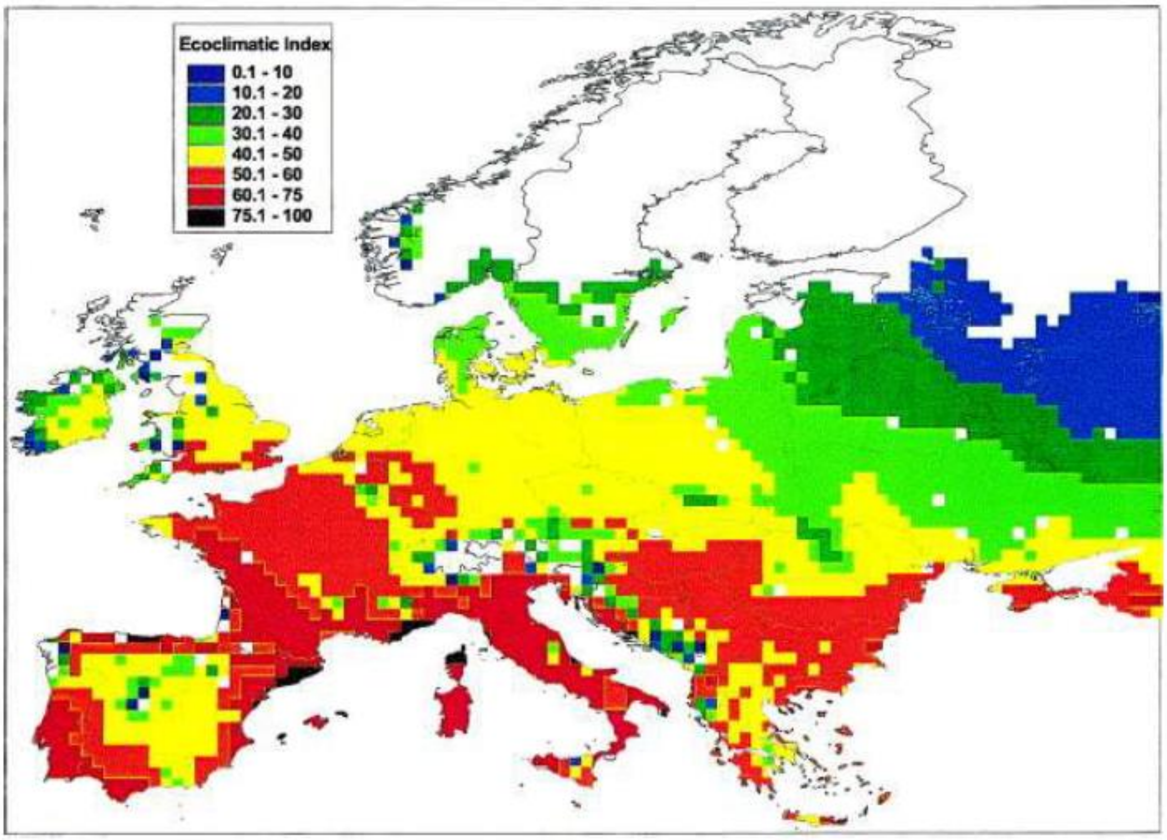

Figure A1. Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB (Ref: MacLeod et al., 2002).

In March 2012 an ALB outbreak was found in Maidstone, Kent. The Forestry Commission and Fera removed more than 2, 000 trees from the area to contain the outbreak. No further outbreaks have been reported in the UK. Analysis of climate data suggests that south east England and the south coast are at greatest risk. MacLeod, Evans & Baker (2002) modelled climatic suitability for outbreaks based on outbreak data from China and the USA and suggested that CLIMEX (the model used) Ecoclimatic Indices of >32 could be suitable habitats for ALB. Figure 25 suggests that Southampton may be vulnerable to ALB under this model.

If an ALB outbreak did occur in Southampton it would pose a significant threat to 51.3% of the trees, not including attacks on shrub species.

The known host tree and shrub species include:

Acer spp. (maples and sycamores)

Aesculus spp. (horse chestnut)
Albizia spp. (Mimosa, silk tree)
Alnus spp. (alder)
Betula spp. (birch)
Carpinus spp. (hornbeam)
Cercidiphyllum japonicum (Katsura tree)
Corylus spp. (hazel)
Fagus spp. (beech)
Fraxinus spp. (ash)
Koelreuteria paniculata

Platanus spp. (plane)
Populus spp. (poplar)
Prunus spp. (cherry, plum)
Robinia pseudoacacia (false acacia/black locust)
Salix spp. (willow, sallow)
Sophora spp. (Pagoda tree)
Sorbus spp. (mountain ash/rowan, whitebeam etc)
Quercus palustris (American pin oak)
Quercus rubra (North American red oak)
Ulmus spp. (elm)

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. England has several confirmed cases of the disease. Ash dieback poses a threat to 4.8% of Southampton's urban forest.

Emerald Ash Borer

There is no evidence to date that 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, perhaps aided by vehicles (Straw et al. 2013). 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 4.8% of Southampton's urban forest.

Giant Polypore

Giant polypore (Meripilus giganteus) is a fungus that can cause internal decay in trees without any external symptoms (Schmidt 2006), causing trees to potentially topple or collapse (Adlam 2014). It is particularly common in urban areas and can also cause defoliation and crown dieback (Schmidt 2006; Adlam 2014). Giant polypore predominantly affects hardwoods such as horse chestnut, beech, cherry, mountain ash and oak. 26.1% of Southampton's urban forest could be vulnerable to giant polypore.

Gypsy Moth

Gypsy moth (GM), Lymantria dispar, 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. Aside from these disparate colonies, GMs range in Europe does not reach as far North as the UK. Some researchers suggest that the climate in the UK is currently suitable for GM should it arrive here and that it would become more so if global temperatures rise (Vanhanen et al., 2007). However, the spread of gypsy moth in the USA has been slow, invading less than a third of its potential range (Morin et al., 2005). If GM spread to Southampton, it would pose a threat of 31.3%.

Oak Processionary Moth

Established breeding populations of oak processionary moth (OPM) have been found in South and South West London and in Berkshire. It is thought that OPM has been spread on nursery trees. The outbreak in London is now beyond eradicating, whereas efforts to stop the spread out of London and to remove those in Berkshire are underway. 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 urticating (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 11.4% of Southampton's urban forest.

Phytophthora ramorum

Phytophthora ramorum was first found in the UK in 2002 and primarily affects species of oak (Turkey oak, Red oak and Holm oak), beech and sweet chestnut. However, it has also been known to occasionally infect European and hybrid larch and kills Japanese larch. Rhododendron is a major host, which aids the spread of the disease. Many cases have been identified in England. Phytophthora ramorum poses a threat to 8.7% of Southampton's urban forest.

Phytophthora kernoviae

Phytophthora kernoviae (PK) was first discovered in Cornwall in 2003. The disease primarily infects rhododendron and bilberry (Vaccinium) and can cause lethal stem cankers on beech. Phytophthora kernoviae is deemed to pose a risk to 26.7% of Southampton's urban forest.

Phytophthora alni

Phytophthora alni affects all alder species in Britain which was first discovered in the country in 1993. Phytophthora disease of alder is now widespread in the riparian ecosystems in the UK where alder commonly grows. On average, the disease incidence is highest is southeast England. Phytophthora alni poses a threat to 1.6% of Southampton's urban forest.

Dothistroma needle blight

Dothistroma (red band) needle blight is the most significant disease of coniferous trees in the North of the UK. The disease causes premature needle defoliation, resulting in loss of yield 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. 2.2% of Southampton's urban forest is potentially at threat from it.

Great Spruce Bark Beetle

The great spruce bark beetle (Dendroctonus micans) damages spruce trees by tunnelling into the bark of the living trees to lay its eggs under the bark, and the developing larvae feed on the inner woody layers. This weakens, and in some cases can kill, the tree. The great spruce bark beetle poses a threat to 0.4% of Southampton's urban forest.

Glossary

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 aboveground 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.

Lesions - any abnormal tissue found on or in an organism, usually damaged by disease or trauma

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.

Phenology - the scientific study of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions

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.

Urticating Hairs - are possessed by some arachnids (specifically tarantulas) and insects (most notably larvae of some butterflies and moths). The hairs have barbs which cause the hair to work its way into the skin of a vertebrate. They are therefore an effective defence against predation by mammals