Forest Research

Treeconomics

Valuing Cardiff's Urban Trees

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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 benefits of trees. 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:

Cardiff City Council **Welsh Government** **Natural Resources Wales**

CARDIFF CAERDYDD

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Copies of this report and of its four-page summary can be downloaded from:

https://www.forestresearch.gov.uk/research/i-tree-eco/

Contents

Key Definitions

Urban areas: are defined as settlements with a resident population over 10,000 (Defra, 2016a). They can be characterised 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.

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., 2016a).

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, and has been used in over 100 cities and 60 countries by urban foresters, communities and businesses to manage urban forests effectively. Eco is a useful tool to discover, manage, make decisions on and develop a strategy concerning trees in Cardiff's urban landscape.

Natural capital: refers to the elements of the natural environment – such as the trees and shrubs of an urban forest - that provide goods, benefits and services to people, such as clean air, food and opportunities for recreation. As the benefits provided by natural capital are often not marketable, they are generally undervalued and inventories limited. This can lead to poor decision making about the management and maintenance of natural capital.

A full Glossary is provided on page 94.

Executive Summary

Urban trees form a resource that provides a range of benefits to human populations living in and around cities. Termed ecosystem services, the benefits provided by urban trees help to offset many of the 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 and exercise, and they can improve social interrelation in communities. These benefits, however, are directly influenced by the management actions that impact upon the overall structure, composition and vitality of the urban forest resource.

A tool well-known for assessing and evaluating urban forests – i-Tree Eco v6.0 – was used to gain a better understanding of the make-up of Cardiff's urban forest and some of the benefits it provides. This information can act as a baseline from which to understand threats, set goals and monitor progress towards optimising the resource. Through i-Tree Eco some of the benefits provided by urban forests cannot only be determined, but also valued. Valuing the services provided by the urban trees of Cardiff can allow Cardiff Council to increase the profile of its urban forest, and thereby help to ensure its value is maintained and improved upon.

The data presented in this report provides detailed information on the structure of Cardiff's urban forest, its composition, condition and public amenity value. It demonstrates that residents of and visitors to Cardiff benefit significantly from urban trees.

In terms of avoided water runoff, carbon sequestration and the removal of three types of air pollutants, Cardiff's urban forest **provides ecosystem services worth £3.31 million per year**. This value is astonishing, yet it is an **underestimate** as it excludes many ecosystem services that i-Tree Eco cannot currently assess, including cooling local air temperatures and reducing noise pollution.

This study captures a snapshot-in-time. It does not consider how the urban forest has or might change over time, or the reasons for this change. However, it does provide a means to make informed decisions on how the structure and composition of Cardiff's urban forest should change in the future, and how to ensure that it is resilient to the effects of a changing climate.

The study was funded by Cardiff City Council and the Welsh Government and carried out by Forest Research.

Cardiff i-Tree Eco Headline Facts and Figures

Structure and composition of the Urban Forest in 2017

Total number of trees (estimate)	1,410,000	
Urban tree density (estimate) (trees per hectare)	100	Pg 20
Total tree canopy cover (estimate)	18.9%	
Number of tree species surveyed	73	
Top three most common species surveyed	Common ash (11%) Sycamore (10%) Common beech (8%)	Pg 22
Land uses where a greater % of surveyed trees were found	Agriculture, including woodlands (34%) Parkland (24%) Residential (17%)	
Proportion of surveyed trees of different sizes (by dbh)	7-20 cm (43%) 20-40 cm (37%) 40-60 cm (14%) 60+ cm (7%)	Pg 27
Proportion of surveyed trees in good or excellent condition	75%	Pg 29
Top pest and disease threat	Chalara ash dieback	Pg 51

Estimated ecosystem service provision amount and value in 2017

Avoided runoff	355,900 m^3 of water (per annum)	**£476,800** (per annum)	Pg 34
Pollution removal	190 tonnes (per annum)	**£940,000** (per annum in terms of NO_2, SO_2 and $PM_{2.5}$ only)	Pg 36
Carbon storage	321,000 tonnes to date	**£76.6 million**	Pg 41
Net carbon sequestration	7,950 tonnes (per annum)	**£1.9 million** (per annum)	
Replacement cost	Amenity value of all trees: **£11.2 billion** (CAVAT) Structural value of all trees: **£309 million**		Pg 48
Total annual benefit	**£3.31 million** (some air pollutants removal, net carbon sequestration and avoided runoff)		
Total benefits: per ha and per capita	**£236 per ha** of study area £9.18 per capita, annually		
The value of these annual benefits over the next 100 years is projected at £44.2 million (discounted Present Value)			Pg 60

Report scope and use

This report provides a baseline on the structure, composition and benefits delivery of Cardiff's urban forest – a dynamic resource whose benefits are enjoyed across Cardiff but are not necessarily optimised in all areas of the city. By showcasing the value of benefits provided by Cardiff's trees, increased awareness can be used to encourage investment in the wider environment.

The assessment presented in this report provides the opportunity to explore a number of areas of interest including:

- maintaining current tree cover
- identifying areas that would benefit from enhanced protection, for example from development
- identifying areas to enhance through new planting to offset known forecasts of loss of tree cover through development or pests and diseases
- identifying areas to enhance direct local benefit.

This report can also be used by:

- those writing policy
- those involved in strategic planning to build resilience or planning the sustainable development and resilience of the city
- those who are interested in local trees for improving their own and others health, wellbeing and enjoyment across the city
- those interested in the conservation of local nature.

Key Conclusions

- Species mix in Cardiff's urban forest should become more diversified, to build resilience to climate change, the threats posed by emerging pests and diseases, and to improve ecosystem service provision across the city.
- The Cardiff urban forest should be managed to bolster the number and improve diversity of mature large stature trees, given that large sized trees provide proportionally more ecosystem services than small stature trees. These large trees are well represented in Cardiff compared to other UK towns and cities, yet may be at risk from future development.
- Of the trees recorded, **about 70% were under private management**. An important resource for the city that is outside of its direct control and is therefore potentially vulnerable to change not directed by a city tree (or urban forest) management strategy. Increasing awareness of the significance of this resource through an education and engagement programme could encourage proactive management, and should be considered an important goal going forward. By the

same notion, a management strategy for Cardiff's urban forest would be beneficial to create targets for the urban forest and monitor success. Monitoring change by repeating an i-Tree Eco study in five to ten years would ensure consistency and comparability.

Photo: An urban tree in mixed residential ground in Cardiff, providing shade as well as aesthetic beauty.

Introduction

The urban forest comprises 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., 2016a). Urban trees provide a range of benefits (widely termed ecosystem services) which make urban areas more enjoyable places to live, support the physical and mental health of residents, and mitigate risks from flooding, climate change, and high urban temperatures and air pollution. If the ecosystem services achieved through urban trees were not in place, urban areas would require unprecedented levels of investment in engineered solutions to obtain the same results.

This report presents the findings of an i-Tree Eco survey and urban forest assessment, undertaken in Cardiff in 2017. It forms a 'baseline', a first step in understanding the urban forest structure and distribution to then undertake and quantify some of the significant ecosystem services Cardiff's trees provide.

i-Tree Eco was developed by the US i-Tree Cooperative[1] to assess the make-up of urban forests and estimate and value some of its benefits. It has been used successfully in over 100 cities globally and has been tested for its suitability for use in the UK. i-Tree Eco is considered fit-for-purpose for valuing UK green infrastructure (eftec, 2013).

Cardiff is one of the fastest growing cities in the UK. With an estimated population size of 361,208 in 2016 (Welsh Government, 2018a) it's projected that by 2035 that the population will reach over 400,000 (CCC, 2017a). The expansion of urban areas to accommodate this growing population, as well as infilling urban areas such as gardens, can put pressure on the urban forest by reducing the number and size of trees able to be planted. Cardiff's canopy cover has already been shown to have declined by 37 ha (2.8%) between 2009 and 2013 (NRW, 2016a).

In this section, we present an introduction to the core concepts of natural capital and ecosystem service provision required to understand the i-Tree approach to urban forest assessment at the local level. This information forms an important cornerstone to help the city council make informed plans to achieve their green infrastructure objectives. It also serves to improve the focus of efforts to invest in the urban forest through the planned intervention to maximise benefit and avoid (potentially costly) loss, through protection and development.

[1] 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

Ecosystem Service Provision

The Millennium Ecosystem Assessment (2005) and the UK National Ecosystem Assessment (2014) provide frameworks to examine the possible goods and services that ecosystems can deliver, according to four categories: provisioning, regulating, supporting and cultural services. The ecosystem services valued by i-Tree Eco, plus other ecosystem services the urban forest may provide, are presented in Table 1 along with the significance of the benefits of each service in Cardiff.

For a more detailed review of ecosystem service provision by urban trees and how this varies depending on the environment, tree structure and composition, and management, see Forestry Commission Research Report 26 (Davies et al., 2017).

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

Table 1. Review of some of the ecosystem services which urban trees provide and the significance of these services to Cardiff. The four ecosystem services which will be discussed in more detail in this report are avoided runoff, air pollution removal, carbon storage & sequestration and habitat provision (darker purple).

Ecosystem service	Role of urban trees	Significance to Cardiff
Avoided runoff	Tree canopies intercept rainfall, reducing the volume of water that forms surface runoff. Flooding from intense runoff is a serious risk in urban areas and increases costs for sewerage treatment.	Surface water flooding caused by runoff of water which doesn't drain away is a common cause of flooding in Cardiff (CCC, 2014). Just over 12,000 people are estimated to be at risk from the more extreme flood events (CCC, 2015).
Air pollution removal	Tree canopies intercept air pollutants, reducing exposure of people to pollutants that can be harmful to health.	Air pollution is linked to 143 deaths per year in Cardiff (PHE, 2014). Four Air Quality Management Areas (AQMAs) have been declared in the city due to high NO_2 levels.
Carbon storage & sequestration	Trees remove CO_2 from the atmosphere and store carbon in their wood, helping to mitigate global climate change.	Cardiff emits around 6 tonnes of CO_2 per head of capita annually (CCC 2017a). Climate change is expected to make Cardiff's climate warmer and wetter by 2050 (ASC, 2016).
Habitat provision	Urban trees support a range of biodiversity in urban areas, providing opportunities for residents to engage with nature.	Cardiff contains many protected areas (SACs, SSSIs) containing woodland habitats, along with a number of protected species.

Cultural value	Trees improve social cohesion by providing spaces to meet. Trees help to create a sense of place and old trees help create a link to local history and nature.	Cardiff respondents said access to the outdoors was a key contributing factor to their well-being (CCC, 2017a).
Noise reduction	Trees can act as a barrier to noise and reduce stress levels from heavy traffic.	84% of Cardiff residents are satisfied with noise levels (CCC, 2017a) but new development may increase noise disruption.
Educational value	Trees and woodlands create learning opportunities for children. Adults' involvement and training in tree management can also develop new skills.	The Public Opinion of Forestry Survey found 47% of Welsh respondents stated woodlands can be used by schools/ educational groups, and 25% believe they support the local economy (Forestry Commission, 2017). Cardiff's unemployment rate in 2016 was at 6% (CCC, 2017a).
Temperature regulation	Urban temperatures are often higher than rural areas. Tree canopies provide shade and water transpiration, reducing local temperatures and the need for air conditioning. This improves people's comfort and reduces CO_2 emissions.	Cardiff's temperatures are expected to increase with climate change, which could be particular risk to those living in more socially disadvantaged neighbourhoods (ASC, 2016). Cardiff's green and blue spaces were estimated to cool the city by an average of 0.71°C, with a calculated worth of nearly £1.5 million (eftec, 2018).
Landscape enhancement	Urban trees can improve the image of places and how people enjoy them, raise property values and increase footfall in commercial areas. Trees can have a restorative effect, improving mental well-being.	More deprived areas tend to have less tree cover (NRW, 2016a). Less than half of surveyed respondents from the South and East of the city agreed that Cardiff has a clean, attractive and sustainable environment (CCC, 2017a).
Recreation	People are more likely to engage in physical activity in greener environments, improving resident's physical and mental health (Kondo et al. 2018).	68% of Cardiff's population live within 300 m of a greenspace (Welsh Government, 2012) and there is generally high satisfaction with parks and open spaces (CCC, 2017a). Cardiff aims to increase active travel by 2021 (CCC, 2017a).

Table 1 shows that many of the ecosystem services provided by urban trees are not quantified or valued by i-Tree Eco. **The value of Cardiff's urban forest presented in this report should therefore be recognised as a conservative estimate** of the value of the full range of benefits that this urban forest provides to the residents of, and visitors to Cardiff.

It is also important to recognise that:

- The v6 i-Tree Eco model provides a snapshot-in-time picture on size, composition and condition of an urban forest. Only through comparison to follow-up i-Tree Eco studies, or studies using a comparable data collection method, can the urban forest be assessed for changes 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:
    - site conditions, 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 and future climate projections; and
    - guidelines on species composition and size class distribution for a healthy resilient urban forest.

Opportunities

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

Social objectives

- Policy: establish new policy to protect and expand all aspects of Cardiff's urban forest, under both private and public ownership.
- Education and advocacy: raise the profile of Cardiff's urban forest as a key component of green infra-structure providing benefits to those who live and work in Cardiff.
- Quality of life: green space provis-ion to support health and well-being through near nature experience.

Economic objectives

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

Environmental objectives

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

Photo: Urban trees providing noise mitigation and habitat provision ecosystem services.

What difference can i-Tree Eco make?

Since i-Tree Eco was first used in the UK, in Torbay in 2011, it has been applied in over 30 UK projects, including in London, Wrexham and Edinburgh. A review of the impacts from a number of these projects identified many of the outcomes that the project can provide (Hall et al., 2018; Hand & Doick, 2018), including:

- Improving understanding of urban forests and their ecosystem service value.
- Identifying emerging threats to the urban forests, such as low resilience to pest and disease outbreaks. This has been used to inform local and regional reports on these threats, by strategies to improve the age, size and species structure of urban forests. The London Victoria BiD i-Tree Eco study in 2011, for example, showed the dependence on London Plane for ecosystem services, therefore suggesting that a more diverse population would be beneficial to increase resilience.
- Informing new tree and woodland strategies, such as in Edinburgh and Torbay.
- Justifying investment in the urban forest, such as securing two £25,000 budget increases in two years in Torbay, or a new Arb. officer post in Wrexham.
- Starting conversations between different local authority departments and helping raise interest in trees beyond arboricultural and parks teams. Since i-Tree Eco projects, trees have been cited in a range of local authority reports including climate change, open space strategies, landscape design and neighbourhood design strategies. These conversations are also not just limited to local authority departments, encompassing Business Improvement Districts, Community groups (such as the Sidmouth Arboretum) and design teams.

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 website 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.forestresearch.gov.uk/research/i-tree-eco or www.treeconomics.co.uk.

The identification, measurement, mapping and caring for trees in the urban environment create opportunities 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.

Methodology

i-Tree Eco uses a plot-based method of sampling, from which the recorded data is extrapolated to statistically represent the whole study area. For this study, 203 plots were randomly selected across the City of Cardiff and 199 were completed. The boundaries adopted for the study and the location of the plots are presented in Figure 1.

The study area was the largest sample area of any i-Tree Eco study in Wales to date, encompassing 14,064 ha and resulting in a sample every 71 ha. This sample density was therefore lower than in other Welsh i-Tree Eco studies (Table 3). The proportion of plots falling into the different land use classes is given in Figure 2.

i-Tree Eco data collection

i-Tree Eco uses a standardised field collection method outlined in the i-Tree Eco Manual v6 (i-Tree, 2018) and this was applied to each plot. Each plot covered 0.04 ha (circle with radius 11.4 m) and from each was recorded the following data collected from each:

- The type of land use, e.g. park, residential
- The percentage distribution of cover present in the plot e.g. grass, tarmac
- The tree and shrub cover
- The percentage of the plot that could have trees planted in it
- Information about trees including:
    - number of trees and their species
    - size of the trees including height, canopy spread and diameter at breast height (DBH) of trunk measured at 1.37 m above ground level
    - whether it was a street tree or if it was in public land (public land included parks, streets and cemeteries)
    - condition of the trees including the fullness of the canopy
    - amount of light exposure the canopy receives
    - amount of impermeable surface (e.g. tarmac) under the tree
    - information about shrubs, including the number of shrubs, species and dimensions of the shrub areas.

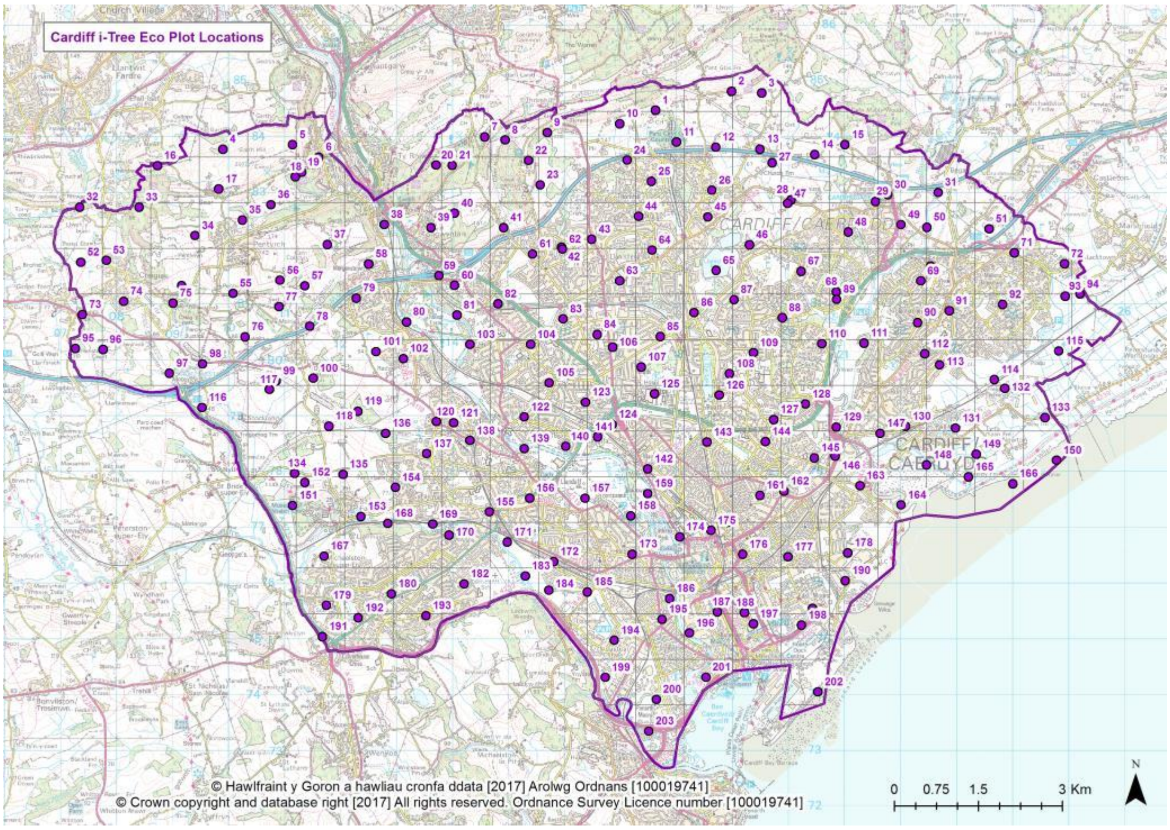


Figure 1. The Cardiff study area. The sample grid and randomised plots are also shown.

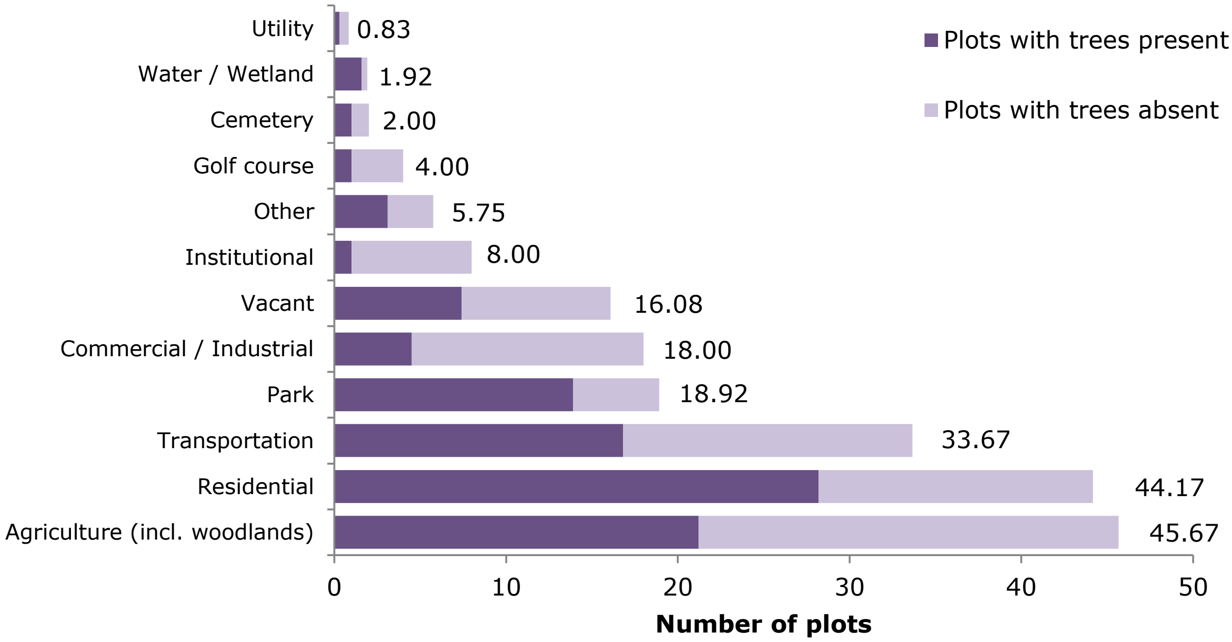


Figure 2. Proportion of plots falling into each of the different land uses (for a definition of land-uses see Appendix 1: Table 18). Plots can contain more than one land use (e.g. where they straddle the boundary between a residential property and the street).

The field data was combined with local climate, phenology (in this case leaf burst and leaf fall) and air pollution data to produce estimates of ecosystem service provision. The full list of outputs generated is listed in Table 2.

Unlike previous versions of Eco, v6 contains the required climate, weather, phenology and air pollution data and so these were not collated for modelling. A summary of calculations is presented below.

Table 2. Outputs calculated based on field collected data.

Outputs	Collected field data inputs
Urban forest structure and composition	Species diversity, canopy cover, age class, condition, importance and leaf area Urban ground cover types % leaf area by species
Annual ecosystem services	Air pollution removal by urban trees for CO, NO_2, SO_2, O_3, $PM_{2.5}$ and a value in £ based on *the UK damage costs for the removal of* NO_2*,* $PM_{2.5}$ *and* SO_2 *or* the US externality cost prices (USEC) for CO and O_3 where UK costs are not available. Annual carbon sequestered and value in £ Rainfall interception and avoided sewerage charges value in £
Replacement costs and functional values	Replacement cost based upon structural value in £ (CTLA - Council of Tree and Landscape Appraisers Method) *Replacement cost based upon amenity value in £ (a CAVAT - Capital Asset Value for Amenity Trees - assessment)* Current carbon storage value in £
Habitat provision	*Foliage invertebrates, blossom and nectar provision, fruit and seed provision.*
Potential insect and disease impacts	*Acute oak decline, Asian longhorn beetle, bleeding canker of horse chestnut, chalara dieback of ash, emerald ash borer, giant polypore, oak processionary moth, Phytophthora alni Phytophthora ramorum, Phytophthora kernoviae, Phytophthora lateralis, Dothistroma (red band) needle blight, spruce bark beetle*

Italic entries denote non-standard i-Tree outputs conducted by the authors

Replacement Cost and Amenity Value

i-Tree Eco provides replacement costs for trees based on the CTLA (1992) valuation method. An amended version of the Capital Asset Value for Amenity Trees (CAVAT) Quick method (Doick et al., 2018) was also used in this study. 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. 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 Cardiff or the wider UK. A risk matrix, devised by the authors, was used for determining the potential impact of priority pests and diseases, should they become established in the urban tree population of Cardiff.

Habitat Provision

Trees and shrubs provide valuable habitats and food for many species, from non-vascular plants such as moss, to insects, birds and mammals. A review of the value of different tree species to UK wildlife by Alexander et al. (2006) is used to examine the relative biodiversity value for urban trees, supplemented with information from Southwood (1961), Kennedy & Southwood (1984), and RHS (2018a). Alexander et al. review a wide range of biodiversity values, giving trees a score from 5 (high value) to 0 (low value). Three examples are shown in the report (foliage invertebrate value, blossom and pollen value, and fruit and seed value). The remaining values are reported in Appendix IV.

Comparisons to Other UK i-Tree Eco Studies

Comparisons of results are drawn from previous UK i-Tree Eco study reports, namely:

- London (Rogers et al., 2015)
- Edinburgh (Doick et al., 2017a)
- Wrexham (Rumble et al., 2014)
- Bridgend (Doick et al., 2016b)
- Tawe Catchment (Doick et al., 2016c)

Summary of Calculations

Variable	Calculated from
Number of trees	Total number of estimated trees extrapolated from the sample plots.
Tree canopy cover	Total tree 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: £0.99 per kg CO (carbon monoxide - USEC), £5.95 per kg O_3 (ozone - USEC), £12.21 per kg NO_x (nitrogen oxides - UKSDC) or £0.89 per kg NO_2 (USEC), £1.96 per kg SO_x (sulphur oxides - UKSDC) or £0.32 per kg SO_2 (USEC) and £33.71 per kg PM (particulate matter – UKSDC) or £206.51 per kg PM (USEC).
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 was the household standard volumetric rate of sewerage charges set by Welsh Water (£1.34 per m^3) in 2017.
Carbon storage & sequestration values	The baseline year of 2017 and the respective value of £65 per metric ton (DBEIS, 2018).
Replacement cost (direct replacement)	The value of the trees based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree), the value is determined within i-Tree Eco according to the CTLA (Council of Tree and Landscape Appraisers) v9 method.
Replacement cost (amenity valuation)	Using the Capital Asset Value for Amenity Trees (CAVAT) Quick method.

Results and Discussion

This chapter presents the results of the i-Tree Eco survey of Cardiff.

Canopy Cover

The **tree canopy cover of Cardiff is estimated to be 18.9%**, which is higher than the canopy cover found in other UK i-Tree Eco studies (Table 3). It is also higher than the 2013 reported average for Welsh urban areas: 16.3% (NRW, 2016a), though it should be noted that NRW's estimate is based on a boundary specific to the built-up areas, excluding many of more rural and wooded areas on the fringe of Cardiff's administrative boundary. The estimate of 18.9% canopy cover ranks Cardiff at 101st out of 312 urban areas which have canopy cover estimates (www.urbantreecover.org).

The urban forest of Cardiff has an estimated tree population of 1.4 million trees. This is a density of 100 trees per hectare, more than estimated in other Welsh i-Tree Eco studies (Table 3).

Ground Cover

Ground cover in Cardiff consisted of 59% permeable materials, such as grass and soil; the remainder consisted of non-permeable surfaces such as tar (asphalt), concrete and cement, which contribute to heating of the urban environment – see box below – and slow precipitation infiltration to soil.

Permeable surfaces can reduce flash flooding. Based on the i-Tree Eco surveys, the percentage of permeable cover in Cardiff is higher than in Bridgend (49%) or Wrexham (52%), and similar to that in London (60%).

Table 3. Outputs from the Cardiff i-Tree Eco survey compared to five other UK surveys.

	Cardiff	London	Edinburgh	Bridgend	Tawe catchment	Wrexham
Study area size (ha)	14,064	159,470	11,468	4,440	6,995	3,833
Total number of trees ('000's)	1,410[1]	8,421	712	439	530	364
Sample density (one plot per [...] ha)	71	221	57	22	28	19
Canopy cover (ha)	2,658[2]	22,326	1,950	533	1,119	652
% Tree canopy cover	19	14	17	12	16	17
Average number of trees per ha	100	53	62	99	76	95

1. This represents 3.9 trees per resident (population of Cardiff estimated as 361,168 in 2016; Welsh Government, 2018a)
2. This is approximately 47 times the size of Cardiff's Bute Park which covers 56 ha (http://bute-park.com/about-bute-park/).

Urban heat island effect

The abundance of buildings and paved areas in urban areas causes an effect known as the 'Urban Heat Island'. This occurs partially due to the lower albedos of surfaces such as asphalt, concrete and brick and stone. Lower albedos mean that larger proportions of the solar energy which encounters the surface is absorbed, warming the surface. A warmer surface also translates into warmer immediate surroundings, causing the Urban Heat Island effect.

This effect can significantly raise air temperature in a city; in London, for example, air temperatures can be up to 10.5°C higher than those in rural surroundings (Doick et al., 2014). However, increasing urban canopy cover is a way in which cities can begin to mitigate urban heat.

Urban Forest Structure

Species Composition

Out of the total 73 tree species identified, the three most common species were common ash, sycamore and common beech. The ten most common tree species accounted for nearly 67% of the trees surveyed (Figure 3). 56% of the trees were native species. 25% of all trees were evergreen and 75% deciduous.

Where trees were present, they most commonly occurred on agricultural land (34%; for definitions see Appendix I), parks (24%) and on residential land (17%; Figure 4). Table 4 provides a breakdown of species composition and canopy cover in the four largest land uses in Cardiff.

The number of trees on publicly-owned land (parks, cemeteries and streets) was estimated at 30%. This leaves the majority of Cardiff's trees in private ownership, which has some degree of risk for management of changes to the urban forest due to its vulnerability, unless protected.

Educating Cardiff's residents on the significance of this important resource can be a way to mitigate this risk. Engagement in stewardship can appeal to those interested in working as a community of good practice, such as observed in Sidmouth where a civic arboretum has been formed through public action (Frediani, 2015).

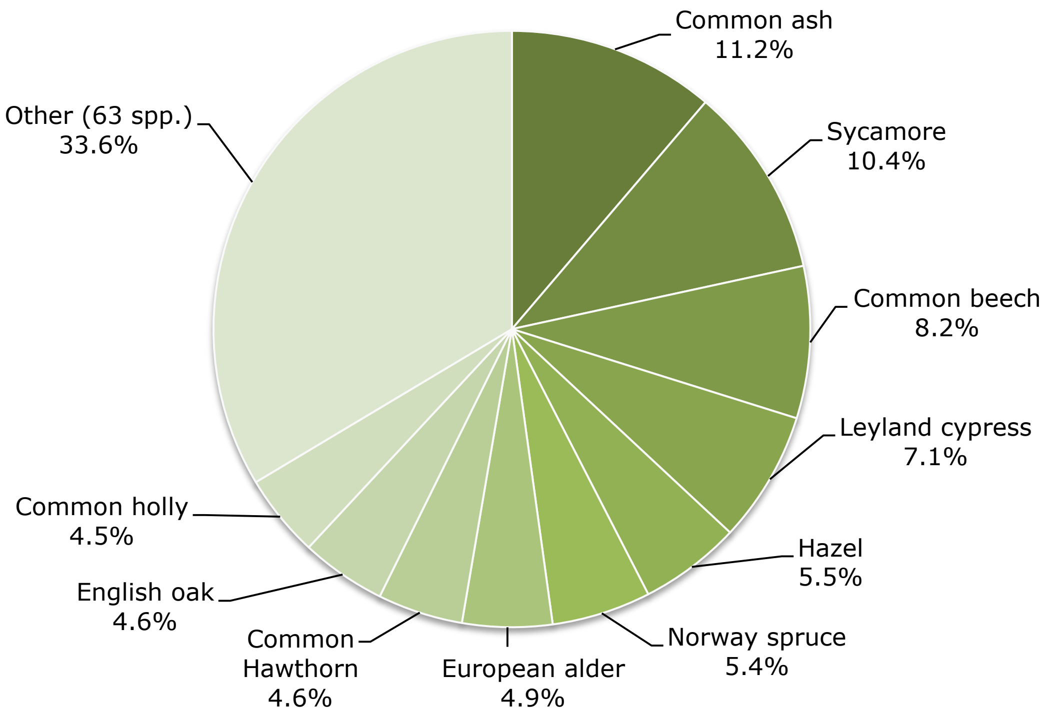


Figure 3. Breakdown of the percentages of the ten most common tree species found in the Cardiff survey.

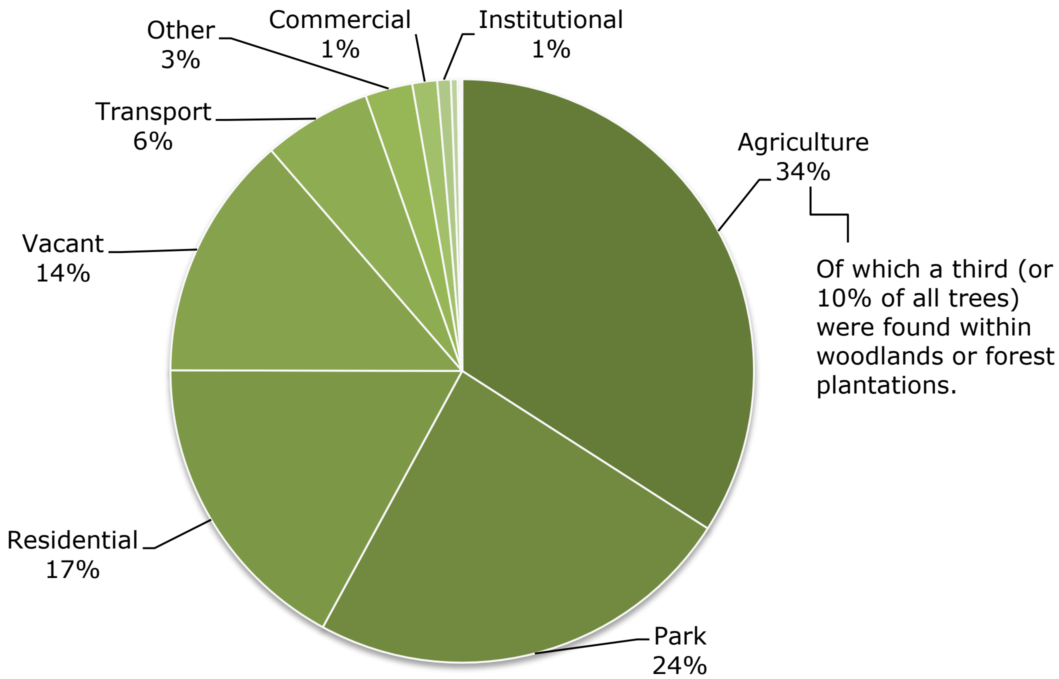


Figure 4. Land use types on which trees were present. Land use types where no trees were found are omitted.

Table 4. Breakdown of species composition for the four land uses with most plots in Cardiff.

	Residential		Park		Transportation		Agriculture	
Percentage of all plots	22%		10%		17%		23%	
Percentage of plots with trees present	64%		74%		50%		46%	
Average canopy cover (%) of plot	8.4%		33%		5.3%		26%	
Average plot plantable area (%)	12.1%		38.3%		5.8%		61.3%	
Species richness	41		26		13		22	
Top 10 species breakdown (%)	Leyland cypress	36	Common ash	18	Common ash	23	Sycamore	15
	Silver birch	7	Common beech	15	Leyland cypress	17	Norway spruce	12
	Sycamore	3	Sycamore	14	Aspen	17	Common ash	10
	Common beech	3	Hawthorn	8	Holm oak	15	Common beech	10
	Apple spp.	3	European larch	7	Norway maple	8	Common hazel	8
	Sweet cherry	3	Hazel	5	Monterey pine	4	English oak	6
	Strawberry tree	3	Common holly	5	Cherry spp.	4	Common hawthorn	6
	Bay laurel	3	English elm	5	Common holly	2	Grand fir	5
	Cherry laurel	3	Silver birch	4	Silver birch	2	Goat willow	5
	Common ash	2	English oak	4	Apple spp.	2	Western hemlock	5
Notes	Most trees were either hedge species (Leyland cypress), or smaller ornamental and fruiting species. Non-native species were common.		Many native and large stature species. Smaller stature species were also present, providing diversity, and some rarer species too, like elm.		Ash was dominant; this is of concern due to ash dieback. There is a mix of introduced and native species, evergreens and deciduous species, but fewer native species than in parks.		A mix of native and non-native species. Trees were either part of hedgerows (42%), in woodlands/ plantations (33%) or as single trees or clusters of trees (21%) in fields.	

Species Composition by Origin

Of those trees identified to species level in the Cardiff i-Tree Eco study, it is estimated that 56% are native to Wales. The origin of tree species impacts their ability to thrive, and resist pests and diseases. New pests and diseases, such as Chalara ash dieback, are emerging. Additionally, stresses such as prolonged exposure to drought and flood are projected to increase due to climate change (Murphy et al., 2009). These factors are leading some Councils to consider further use of exotic species. Exotic species tend to have fewer pests associated with them due to being removed from the home range of their specialist predators and diseases (Connor et al., 1980). Trees from warmer climates may also be able to better withstand the effects of climate change (RHS, 2018b). However, exotic species can disrupt native ecosystems by changing the available niches for wildlife to fill (Townsend et al., 2008). They also support fewer native animals (Kennedy & Southwood, 1984), and can become invasive (Mitchell & Power, 2003). A balance of native and non-native species may provide the most resilient solution.

Species Diversity

A total of 73 tree species were encountered during the study (for a full list of tree species see Appendix II - Species Dominance List). This is higher than the species diversity identified in Bridgend (60 species) and Wrexham (54 species), though lower than recorded in the Tawe catchment (88 species) i-Tree Eco study.

Santamour (1990) recommends 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%. Two species exceeded the 10% guideline (common ash and sycamore). No genus exceeded 20% frequency and no family exceeded 30%. Table 5 outlines the top three species, genus and family frequencies in the Cardiff survey.

Table 5. Top three frequency tree species, genus and family.

	1st		2nd		3rd	
Species	**Ash**	**11.2%**	**Sycamore**	**10.4%**	Beech	8.2%
Genus	*Acer*	12.6%	*Fraxinus*	11.8%	*Fagus*	8.5%
Family	*Betulaceae*	17.5%	*Fagaceae*	14.7%	*Pinaceae*	12.9%

Bold entries denote groups exceeding the guidelines outlined by Santamour (1990) of no. species exceeding 10%, no. genus 20% and no. family 30

Diversity Index

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, taking into account whether the population is dominated by certain species.

The mean diversity score of Cardiff's urban forest is 3.3 according to the Shannon-Wiener index. The highest diversity of trees was found in residential areas (2.9) and lands categorised as Agriculture, or Vacant (2.7) (Figure 5). There was very low diversity on Institutional and Commercial land use types where the main tree species were silver birch and alder.

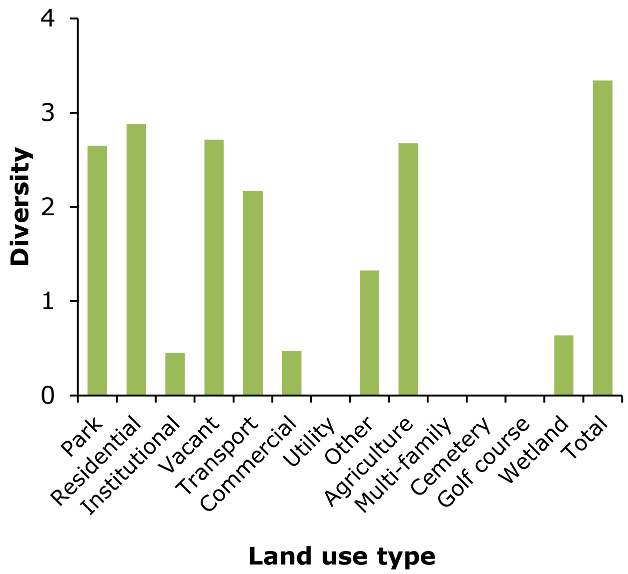


Figure 5. Shannon-wiener diversity index scores for trees on different land use types in Cardiff.

Targeting management for greater diversity

Currently, there is an over reliance on common ash and sycamore in Cardiff (both accounting for >10% of Cardiff's urban forest). This leaves the city vulnerable to emerging pests and diseases that affect these predominant species (see Pest and Disease section).

Selecting trees to broaden the variety of species and increase the diversity offer of Cardiff's urban forest will also increase resilience to the impacts of a changing climate, while also increasing the public amenity value and providing greater support to biodiversity.

Most trees are in agricultural land, parks and residential areas. Influencing agricultural and residential selection of trees is challenging because land designated as such is owned by private individuals, with different land use objectives. In many cases tree species are selected based on their amenity and ability to provide shelter or to screen the property. Benefits for the wider community are less likely to feature as a priority. Regulatory control for important amenity trees, such as through the planning system, can be useful in this regard. However, there is also a need for education and outreach to the residents of Cardiff so that trees are more widely appreciated and protected.

Size Class Distribution

The size distribution of trees is important for a resilient population. Large trees frequently provide more ecosystem services than small ones, compared to their costs (Sunderland et al., 2012; Hand et al. 2018, a,b). Mature trees, whether of small or large stature, will provide greater levels of some ecosystem services than younger trees. Therefore, planting more large stature trees and supporting more trees to reach maturity and thus larger size will increase the ecosystem service delivery per tree of the urban forest. To maintain an on-going level of mature trees, young trees need to be planted in a surplus to allow for mortality.

Richards (1983) suggested the ideal street tree distribution to ensure a healthy stock is 40% of trees with a DBH <20 cm, 30% of trees with DBH from 20 to 40 cm, 20% of trees with DBH from 40 to 60 cm and 10% of trees with DBH >60 cm.

It is estimated that trees with a DBH <20 cm constitute 42.9% of the total tree population in Cardiff (Figure 6a). The number of trees in each DBH class then declines successively. Trees with a DBH >60 cm make up for 6.9% of the tree population, which is lower than the 10% value recommended by Richards (1983). However, Cardiff performs well in comparison to other Welsh i-Tree Eco studies which reported 4% or fewer trees were >60 cm.

Analysis of only large stature trees[2] shows that trees with DBH >60 cm and trees with DBH from 40-60 cm account for 7.7% and 14.0%, respectively (Figure 6b). At the moment there is a slight shortage of trees that will mature into large diameter trees in the near future.

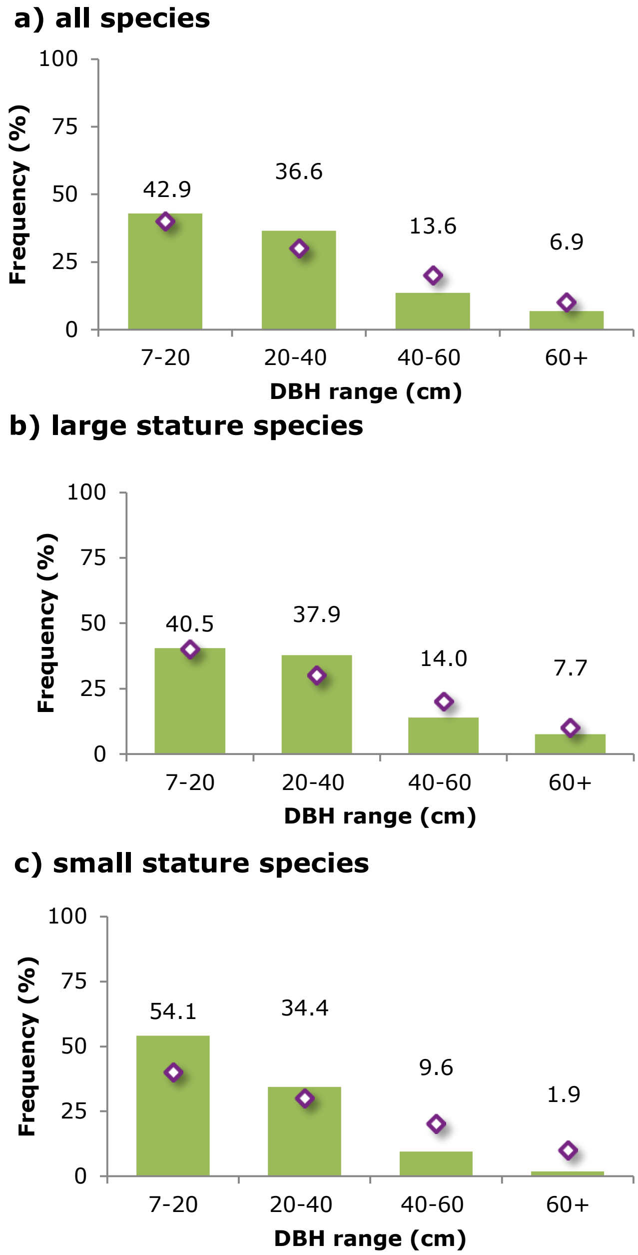


Figure 6. DBH ranges of (a) all measured trees, (b) large stature trees only, and (c) small stature trees only (data values are shown for clarity). Diamonds represent recommended frequencies for that DBH class by Richards (1983) i.e. 40, 30, 20, 10%.

[2] Large stature trees are defined as trees that attain a maximum height greater than 12 m.

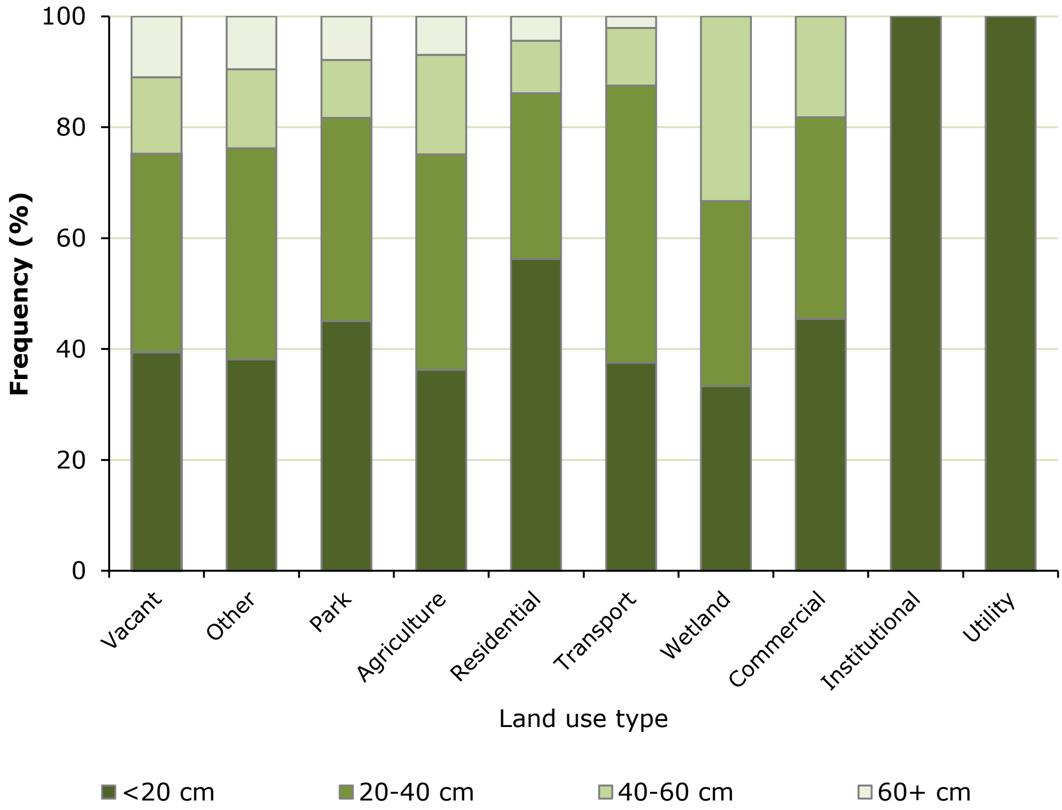


Figure 7. Proportion of diameter size classes per land use type, ordered from left to right by proportion of trees >60cm. A missing value denotes land use types where no trees were found in that size class.

The distribution of tree sizes across the different land uses of Cardiff is shown in Figure 7. Institutional and utility areas only held small trees (<20 cm DBH), and the majority of trees in residential areas were also small trees. Large trees (>60 cm DBH) were highest in proportion on vacant land, parks and agricultural land (excluding the "other" land use category; Figure 7).

Size matters

UK urban areas usually have many trees from the lower size classes (Britt & Johnson, 2008). The decline in large stature trees identified in Cardiff (NRW, 2016) and elsewhere in the UK (London Assembly, 2011) is of concern given the additional benefits these large trees provide and the length of time it takes for small trees to grow into large trees. Cardiff has a tree size class distribution that is better than that of most towns and cities where i-Tree has been applied, but still has a slight shortage of mature large trees (DBH >40 cm).

Fortunately, there is a high proportion of small and, in particular, medium sized trees, providing a reservoir that can be fostered, through careful management, to maturation. These would provide for future generations the benefits of a canopy cover with a higher proportion of large trees, through proportionally more carbon storage, air pollution removal and avoided surface water run-off. A programme of planting would also ensure an on-going presence of small, young trees. A tree planting strategy for Cardiff would be one way to address this.

Urban planners in Cardiff have an opportunity to explore these findings while seeking to continue to conserve and expand the range of tree size classes across all land-use types. Such a strategy could explore what can be done to improve mature trees safely growing alongside highways and in cemeteries where currently no trees were identified in this study.

To illustrate the different ecosystem service delivery of trees of different stature, two trees within this study were selected for comparison: a young ash tree (13 cm DBH), and a mature ash tree (52 cm DBH). The mature tree stores 20 times the carbon, and has ten times the carbon sequestration rate. For avoided runoff services and pollution removal: both were approximately 15 times greater in the mature versus the young tree.

Tree Condition

Condition measures of trees are related to the loss of leaf area from the crown, which is damaging to provision of ecosystem services. It is a useful indicator of potential pest or disease presence, trees in inhospitable locations, or under poor management, and the potential need for further enquiry. For example, follow-up surveys may be targeted at specific species where a trend is observed.

The condition of Cardiff's trees was: 49% of trees in excellent condition, 26% in good and 12% of trees in fair condition[3] (Figure 8). A total of 13% of Cardiff's

[3] Conditions: excellent = <1% dieback; good = 1-10% dieback; Fair = 11-25%; poor to dead rating = >25% dieback (Nowak et al 2008). For full definition see Appendix I.

trees are estimated as being in 'poor', 'critical', 'dying' or 'dead' condition (Figure 8). A proportion of dead trees in an urban forest is important because of their contribution to biodiversity. Across land uses, transport had the fewest trees in excellent condition, while vacant land had the greatest proportion of trees in either critical or dying condition.

Tree condition across Cardiff was worse than that reported for Bridgend (87% of trees were in excellent condition). Condition in Cardiff was more similar, but still poorer, than in Wrexham (58% excellent, 13% in the poor to dead condition categories).

Figure 9 shows the condition of the top ten most commonly encountered trees across Cardiff and reveals that hawthorn and alder had the lowest proportion of trees in 'excellent' condition; on the other hand sycamore and English oak had a high proportion of their total population in the 'excellent' category.

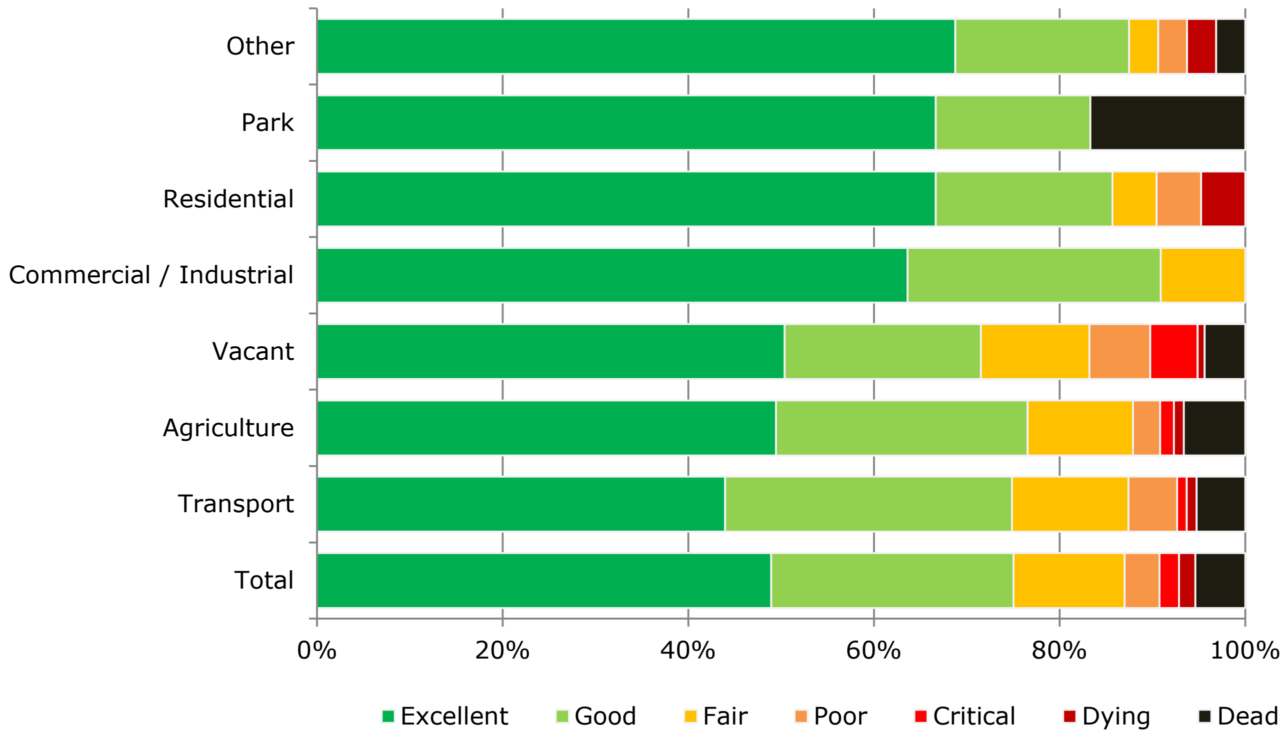


Figure 8. Condition of the total tree population surveyed and by land use ("Other" includes institutional, other, water/wetland, utilities and golf course combined).

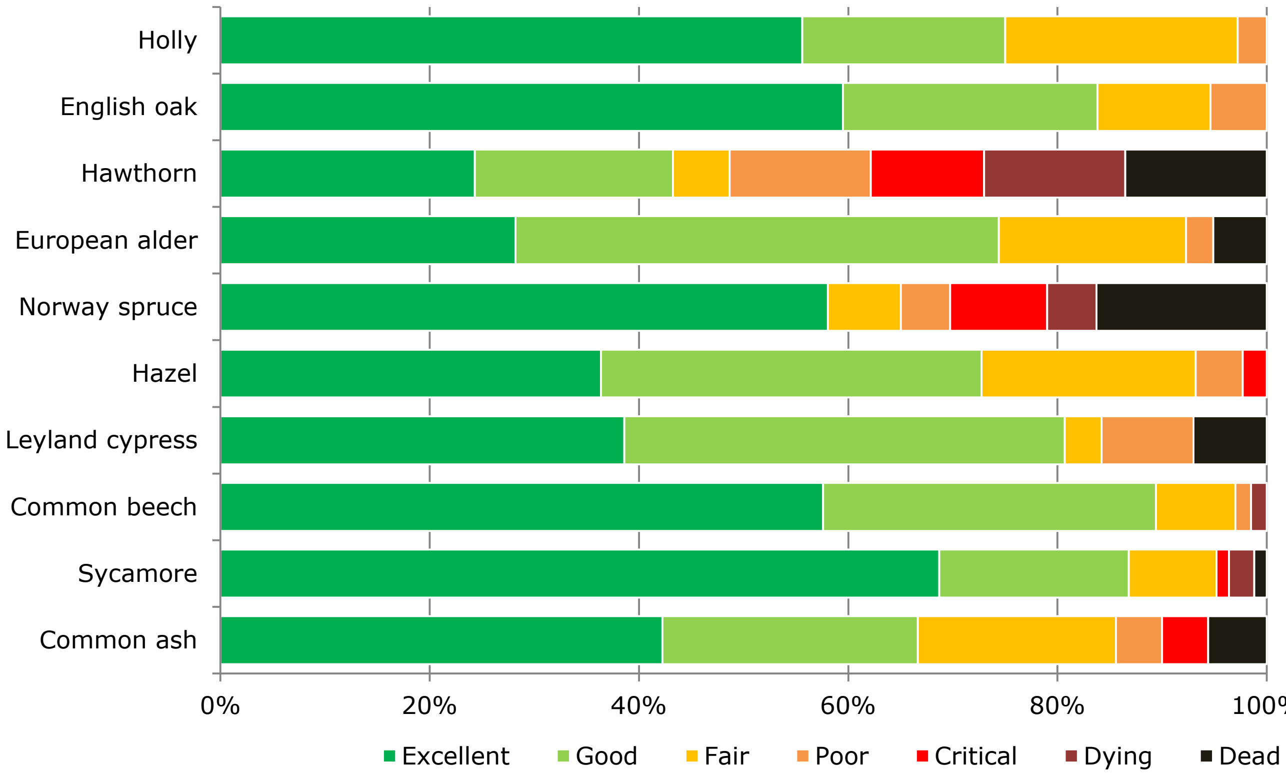


Figure 9. Condition of the top ten most commonly encountered trees across Cardiff.

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 Cardiff's trees is 126.2 km^2. Common beech, common ash and sycamore provide the most leaf surface area (15%, 12% and 8% of the total leaf area of Cardiff's urban forest, respectively; Figure 10).

Dominance value is calculated in i-Tree Eco from 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 Cardiff study, by importance value, were those which appeared in greater numbers, - such as ash and sycamore, and those with large leaves, such as beech (Figure 10).

A list of the dominance values for all tree species encountered during the study is presented in Appendix II - Species Dominance List.

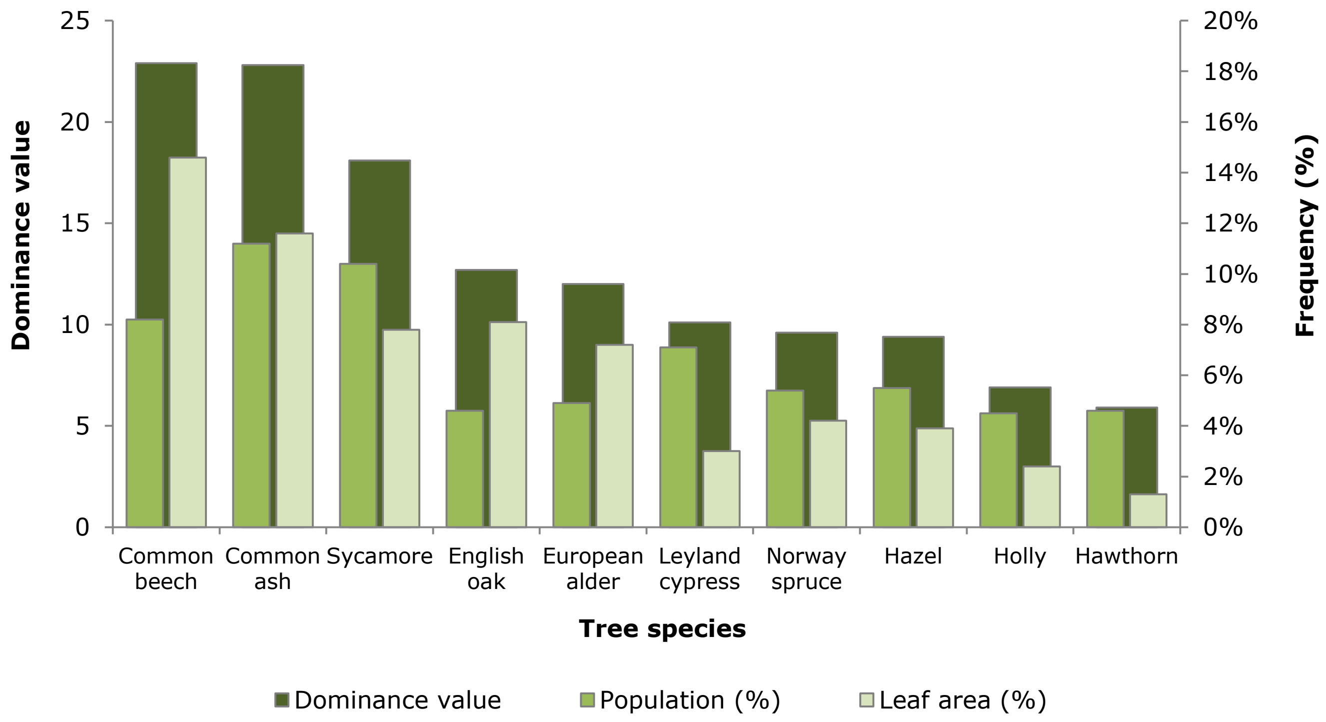


Figure 10. Dominance value of the ten most important tree species in Cardiff, along with their associated percentages of population and leaf area.

i-Tree Eco dominance value

The scientific models that underpin i-Tree Eco reveal a direct relationship between leaf area and the provision of ecosystem services. Thus, in i-Tree Eco, Dominance Value is the sum of leaf area and population size. If the most common trees have larger leaves or large tree canopies, then they tend to rank higher in dominance.

Also known as the Tree Importance value, this relationship is more often termed the Tree Dominance value to avoid assumptions that these are the tree species that should form the core of any future planting strategy. Rather, it shows which species are currently delivering the most benefits based in their population and leaf area.

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

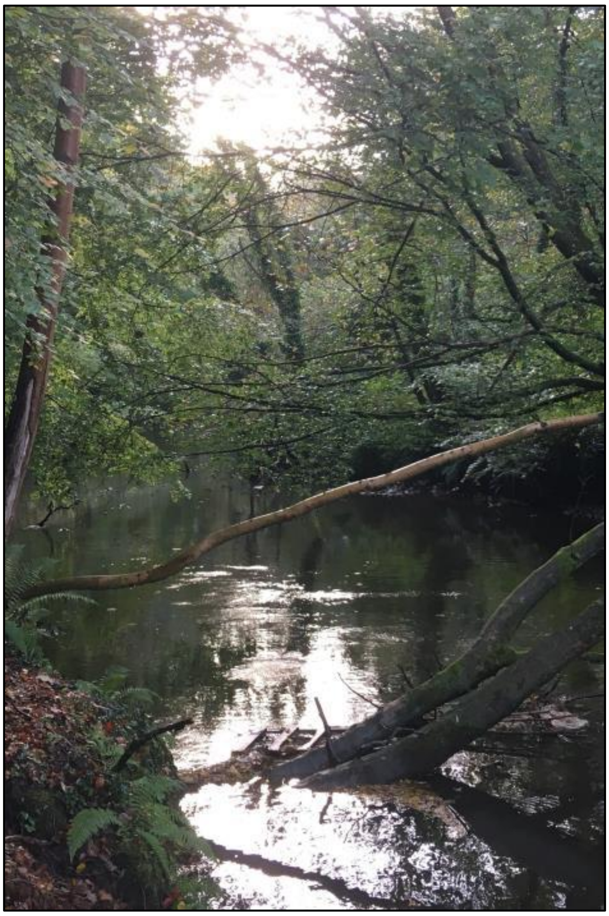
Large evergreen trees, such as Norway spruce and Scots pine, are important for year-round provision of ecosystem services. They are important for achieving a high level of resilience in the long term and enhancing ecosystem service delivery via diversity of species and provision of a structurally diverse urban forest.

Ecosystem Services

Avoided Surface Water Runoff

The issue

Flooding is a serious concern for many towns and cities in the UK, causing damage to property, stress and a risk to life. Urban areas can be particularly vulnerable to surface water flooding, where rainfall may be unable to drain away due to high coverage of impervious surfaces, or because the infrastructure is out-dated. In high rainfall events, flooding can ensue.



How can trees help

Trees can ameliorate this problem by intercepting rainwater, retaining it on their leaves and bark, and absorbing some into their tissues. The roots of trees can also increase natural drainage; this is particularly important for situations where the surface around the trees is permeable allowing the water to infiltrate into the soil instead of flowing into the drainage system (although this is not calculated within i-Tree Eco).

Cardiff's trees

Trees in Cardiff intercept an estimated 355.9 thousand m^3 of water per year. This equates to 25% of the total water volume capacity of Llanishen reservoir[4]. Based on the standard local rate charged for sewerage[5], this saves **£476,800 in avoided sewerage charges across Cardiff each year**. By individual tree species, common beech intercepts the most water (51.7 thousand m^3 per year), worth some £69.2 thousand in avoided sewerage charges (Figure 11).

[4] Based on value of 1,440,909 m^3 of water in LLanishen reservoir (https://en.wikipedia.org/wiki/Llanishen_Reservoir)

[5] Based on Welsh Water's 2017/18 value for the household standard volumetric rate of sewerage charges: £1.3398 per m^3 (Welsh Water, 2017).

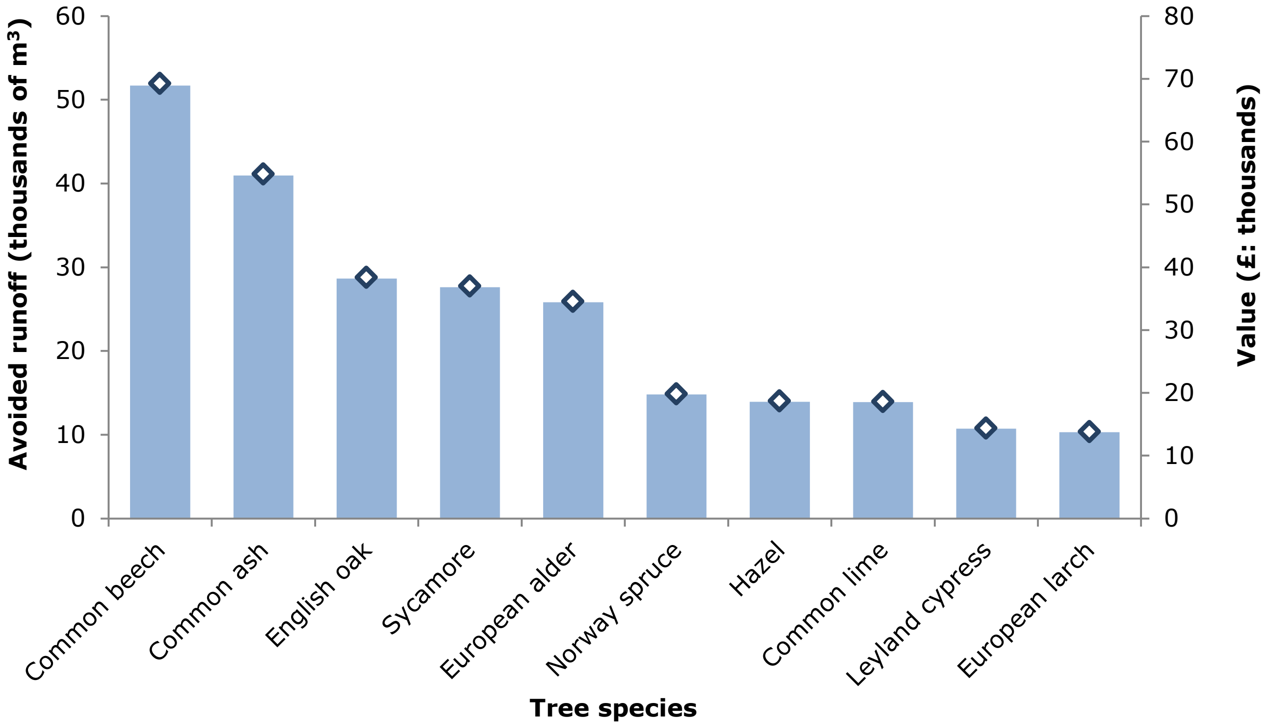


Figure 11. Avoided surface water runoff per year provided by urban trees in Cardiff (columns) and their associated value in avoided sewer costs (diamonds).

Rainfall interception by urban trees

Trees passively intercept rainfall by retaining it on their leaves and absorbing some into their tissues. They ease drainage into and through soil. Trees play an important role in ameliorating the impact of storm water and help reduce the risk of flooding. Trees with large canopies are particularly useful in this regard and across Cardiff beech, ash and oak trees provide a valuable storm water interception service.

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 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 (e.g. see Niinemets & Valladares, 2006).

Planting for interception can 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 mentioned above. Trees can provide a positive contribution to a SUDS system.

Air Pollution Removal

The issue

Air pollution leads to a decline in human health, a reduction in the quality of ecosystems and it can damage buildings (Table 6). Cardiff has one of the poorest air quality in Wales, with the highest NO_2 concentrations in Wales for residential areas (CCC, 2017a). To address this four air quality management areas (AQMAs) have been declared in Cardiff (CCC, 2017a; Figure 12). A study by Public Health England estimated that in Cardiff 143 deaths were attributable to fine particulate air pollution in 2010 (PHE, 2014).

How can trees help

Trees and shrubs can mitigate the impacts of air pollution by directly reducing concentrations of airborne pollutants. Plants absorb pollutants through their stomata, or simply intercept pollutants on their surfaces (Nowak et al., 2006). This leads to year-round benefits, with bark continuing to intercept pollutants throughout winter (Nowak et al., 2006). Plants also reduce local temperatures by providing shade and transpiring, reducing the rate at which some air pollutants, such as O_3, are formed (Jacob & Winner, 2009). However, trees can also contribute to O_3 production by emitting volatile organic compounds (VOC's) that react with other pollutants such as NO_x emitted by vehicle exhaust fumes (Lee et al. 2006). i-Tree Eco reports biogenic emissions of monoterpene and isoprene, the most important naturally emitted VOC's (Stewart et al., 2002). i-Tree Eco takes the release of VOC's by trees into account to calculate the net difference in O_3 production and removal.

Table 6. Urban air pollutants: health effects and sources.

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

Source: www.air-quality.org.uk

Cardiff's trees

It is estimated **that Cardiff's urban forest removes 190 tonnes of airborne pollutants** per year, including NO_2, O_3, SO_2, CO and $PM_{2.5}$. O_3 and NO_2 are removed in greatest quantities. This demonstrates that although trees can contribute to ground-level O_3 formation, they remove more than they produce.

NO_2 is the most critical air pollutant in Cardiff and $PM_{2.5}$ is of national concern. Both pollutants are caused in part by transport. **It is estimated that Cardiff's trees removes approximately 1.8% of NO_x and 10.5% of $PM_{2.5}$ emissions from transport in Cardiff**[6]. The pollution removed from the atmosphere can be valued to aid interpretation of this data. In both the USA and the UK, pollutants are valued in terms of the damage they cause to society. However, these are valued using different methods in each country: United States Externality Costs in the US (USEC) and Social Damage Costs (UKSDC) in the UK. The UK method does not cover all airborne pollutants (Table 7) because of the uncertainty associated with the value of removing some airborne pollutants, and 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, the removal of these pollutants from the atmosphere is worth **£940,000**[7] (Table 7; Figure 13). Using the US valuation system, pollution removal is worth £3.6 million are removed by urban trees in Cardiff each year (Table 7).

[6] Calculated from the total transport emissions of Wales for 2013 (NO_x 22.35 kt, PM_{10} 1.377Kt, Welsh Government, 2018b), where it is estimated 9.5% of these values are attributable to Cardiff based on the number of cars in Cardiff (152,341; Cardiff Research Centre, 2012) versus in Wales (1.6 million; ONS, 2012).

[7] Using the central "domestic" emission source for NO_x, SO_X and PM_{10}

The volume of airborne pollutants varied over the year, with a seasonal pattern evident in the removal of O_3, which was removed in higher volumes during spring and summer (Figure 14). This is because O_3 is a product of the combination of VOC's and NO_x, which are also removed in greater volumes in summer.

The production of O_3 is also more prevalent in warm temperatures (Sillman & Samson, 1995). In addition, this creates a diurnal pattern, with O_3 levels higher during the day than at night (Nowak et al., 2000).

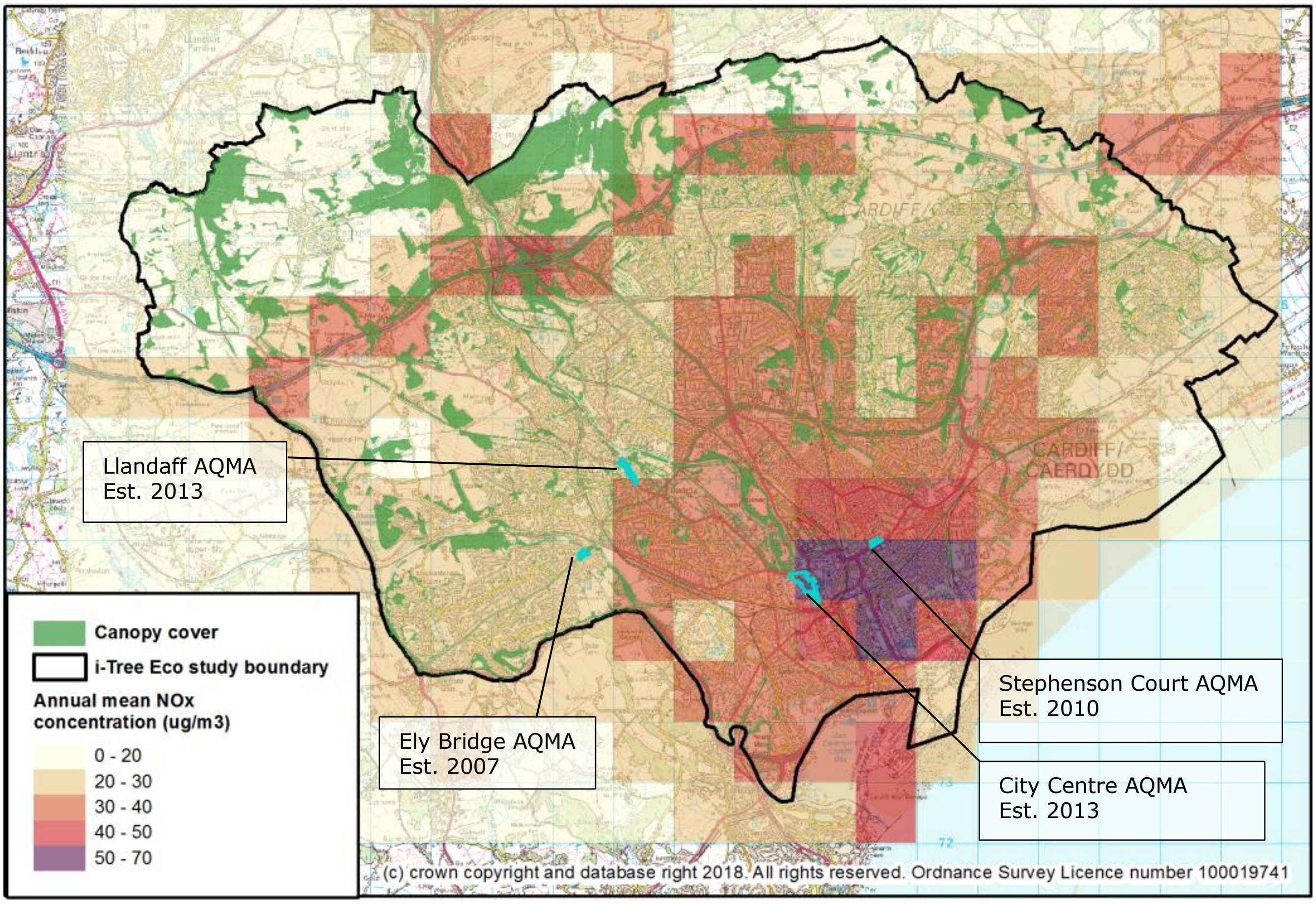


Figure 12. Map of modelled NOx mean concentrations for Cardiff for 2016 (Defra, 2016b) overlapped with tree canopy cover (mapped by NRW, 2016b). The four Air Quality Management Areas (AQMAs) are shown with establishment dates which have all been declared due to exceedances of the annual mean NO_2 air quality standard (40 ug/m^3).

Table 7. Amount of each pollutant removed by Cardiff's urban forest and its associated value. USEC denotes United States Externality Cost and UKSDC denotes UK Social Damage Cost.

Pollutant	Amount removed (tonnes)	US value (£/tonne)	US Value (£: USEC)	UK value (£/tonne)	UK Value (£: UKSDC)
CO	1.08	984	1,051	n/a	n/a
NO_2	37.87	888	33,626	12,205	462,168
O_3	129.36	5,948	769,440	n/a	n/a
$PM_{2.5}$	13.71	206,510	2,830,507	33,713	462,084
SO_2	8.05	323	2,601	1,956	15,750
TOTAL	190.06		3,637,234		940,001

n/a = not available

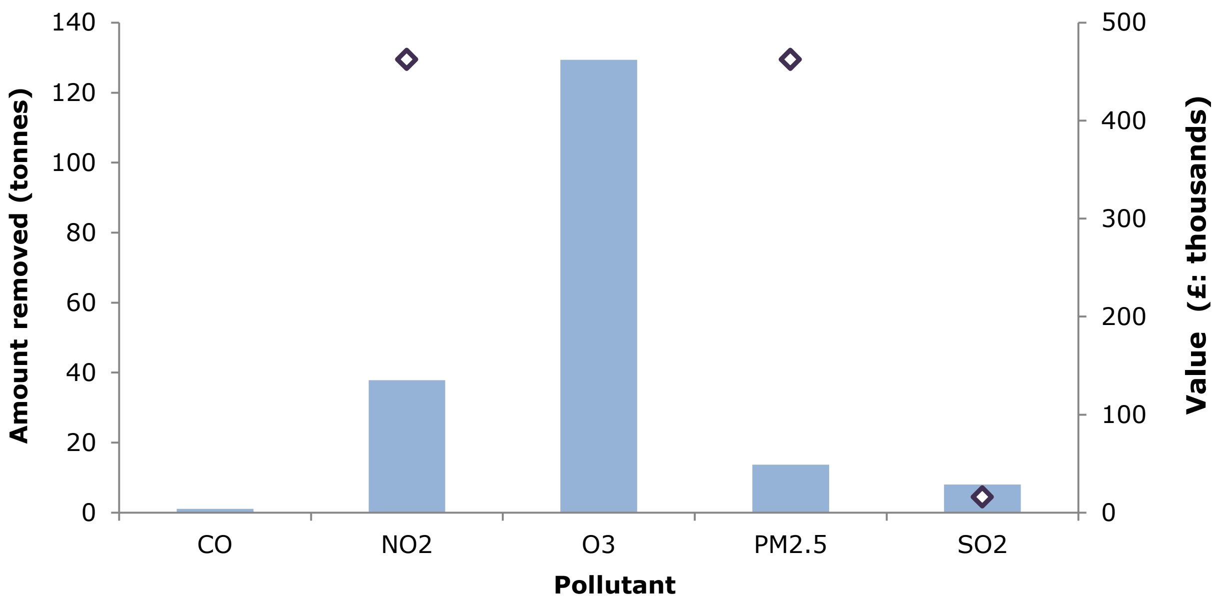


Figure 13. Mean quantity of pollutants removed by urban trees in Cardiff (columns) and the associated value (diamonds; valued using UKSDC). Note no UK values are available for CO or O_3.

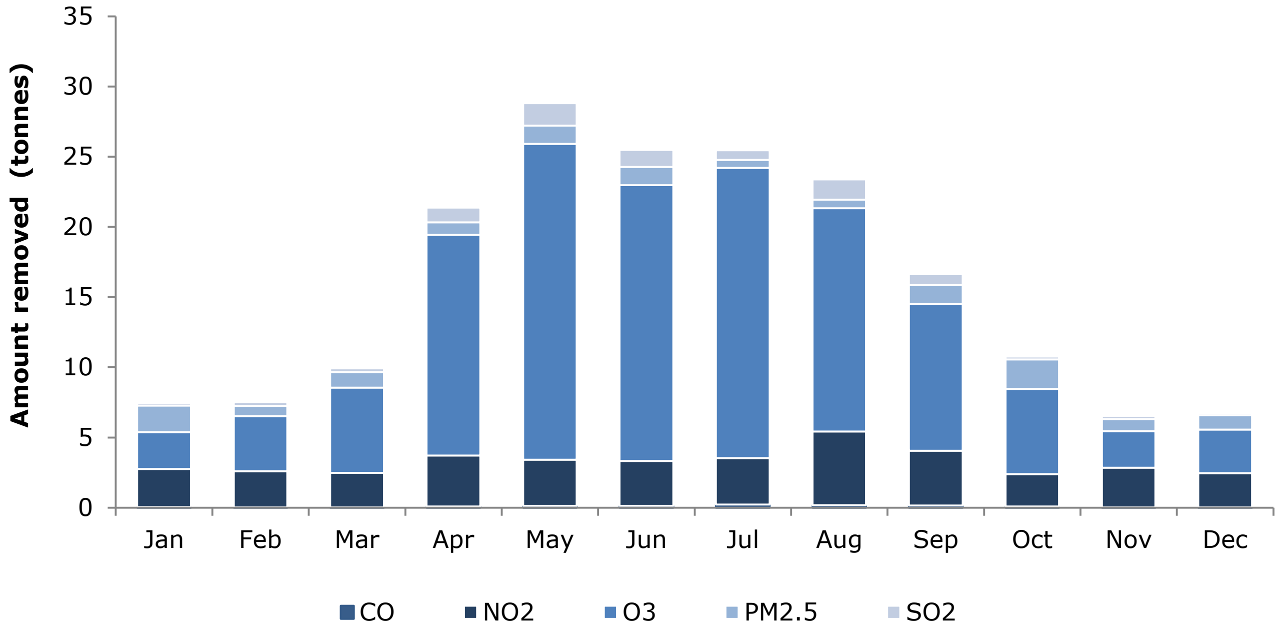


Figure 14. Amount of pollutants removed by Cardiff's urban trees on a monthly basis.

Air pollution removal by urban trees

Air pollution is recognised by the Welsh Government as a critical threat to the health and well-being of urban populations (Welsh Government, 2017). Cardiff has one of the poorest levels of air quality in Wales (CCC, 2017a). In particular, high levels of NO_2 above the statutory limit for NO_2 (annual mean of 40µg/m^3) has led to the designation of four Air Quality Management Areas (AQMAs) in Cardiff. The City of Cardiff Council (CCC) are committed to reducing NO_2 levels below the statutory limit in the shortest time possible (Welsh Government, 2018c). However, projected levels of pollution indicate that Cardiff will continue to exceed EU and UK Air Quality Directive Limit Values for NO_2 beyond 2020 (Welsh Government, 2018c). Road traffic emissions are the principal contributing factor to poor air quality in Cardiff (Defra, 2015a).

In order to improve the air quality in Cardiff, action needs to be taken across the city as whole. Urban trees cannot address the root cause of poor quality: primarily traffic emissions, but their role in contributing to improving air quality is recognised in Welsh Government guidance (Welsh Government, 2017). Trees can help to improve local air quality by intercepting pollutant particles in the air, but also by encouraging more active forms of travel, creating a buffer between traffic emissions and pedestrians and having a potentially calming effect on drivers leading to smoother driving (Welsh Government, 2017). Careful site selection, design of tree layout, species selection and integration with other air quality management strategies can help improve air quality. TDAG's guide 'First Steps in Air Quality for Built Environment Practitioners' (2018) provides examples of how trees can be incorporated into urban areas to mitigate poor air quality.

Carbon Storage and Sequestration

The issue

Increasing carbon dioxide in the atmosphere is a key contributor towards global climate change. At the local level, climate change is projected to both raise summer temperatures and increase winter rainfall in Cardiff (CCC, 2017a). Through the Environment (Wales) Act 2016, Wales is committed to reducing its net carbon emissions by 80% by 2050.

How can trees help

The urban forest is 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 climate change. Large trees are particularly important carbon stores. Across a city, net carbon sequestration can be negative if emission from decomposition is greater than uptake by growing trees.

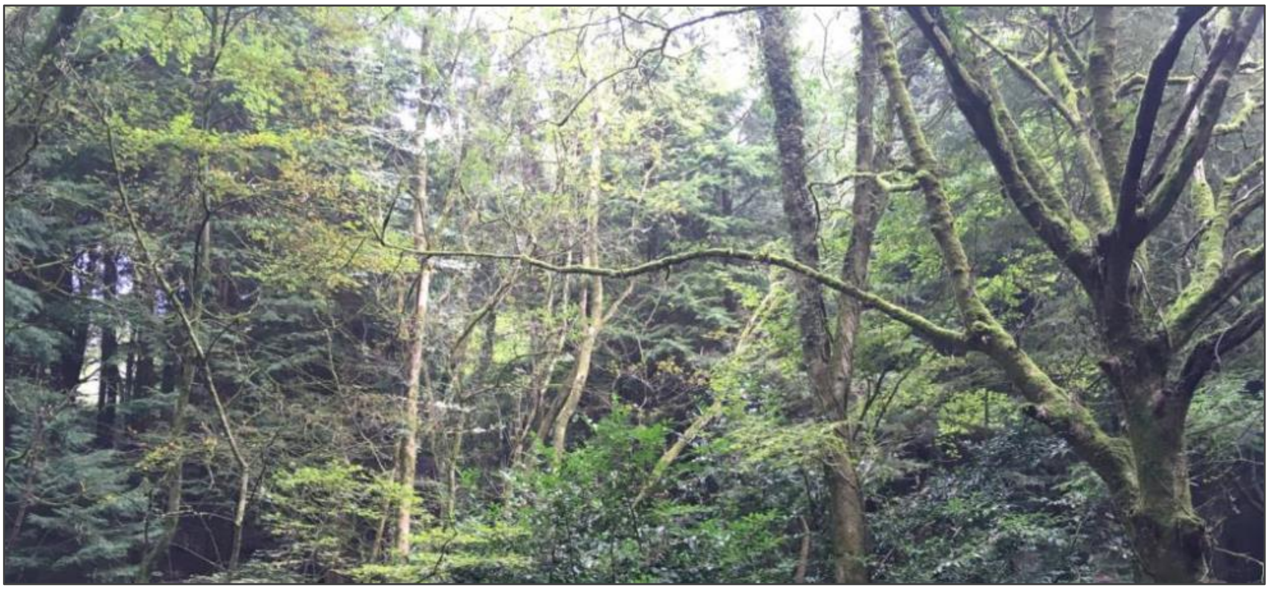
Cardiff's trees

It is estimated that **Cardiff's trees store a total of 321,000 tonnes of carbon in their wood.** This is equivalent to the annual carbon emissions produced by **210,206** households, around 1.4 times the number of households in Cardiff[8]. Alternatively, this is equivalent to the annual CO_2 emissions of **568,143** cars[9].

Similarly to leaf area, carbon storage depends not only on the number of trees present, but also their characteristics. In this case, timber density and quality is important. Larger trees store more carbon in their tissues. English oak, for example, makes up 4.6% of Cardiff's estimate urban tree population, but is responsible for storing 14.5% of the total carbon; ash on the other hand, makes up 11.2% of the tree population in Cardiff and stores 10.4% of the carbon (Figure 15).

[8] Based on an average UK household emission of 5 tonnes of CO_2 per year in 2010 (Palmer & Cooper, 2012) and 151,243 households estimated in Cardiff in 2016 (Welsh Government, 2017).

[9] Based on average emissions of 157g/CO_2 per km (cars registered after 2001, Department for Transport 2014), with the average UK car travelling 13,197 km per year (Department for Transport, 2013).



The carbon in trees can be valued within the framework of the UK government's carbon valuation method (DBEIS, 2018). This is based on the abatement costs of meeting the UK's carbon reduction targets. These social values of carbon are split into two types: traded and non-traded. Traded values are only appropriate for industries covered by the European Union Emissions Trading Scheme. Carbon storage or sequestration by trees does not fall within this category so non-traded values are used instead. Within non-traded values, there are three pricing scenarios: low, central and high. These are used to reflect uncertainties in determining future carbon values, including in relation to future fuel prices. Based on the central value for non-traded carbon for 2017[10], **it is estimated that the carbon in the current tree stock is worth £76.6 million.**

[10] The 2017 value for 1 tonne of carbon is £238, based on the non-traded value of 1 tonne of CO_2 equivalent as £65. This value for CO_2 equivalent is projected to rise to over £300 per tonne in 2060 (HM Treasury, Greenbook, 2018)

The gross amount of carbon sequestered by the urban forest in Cardiff each year is estimated at 9,500 tonnes. Taking into account the number of dead trees, which release carbon into the atmosphere, **Cardiff's urban forest is estimated to sequester 7,950 tonnes of carbon per year net**; this **estimated amount of carbon is worth £1,898,000** (Figure 16). The net sequestration rate is equivalent to the annual emissions from **14,067 cars**. It is also equivalent to the estimated annual emissions of **5,205 households.**

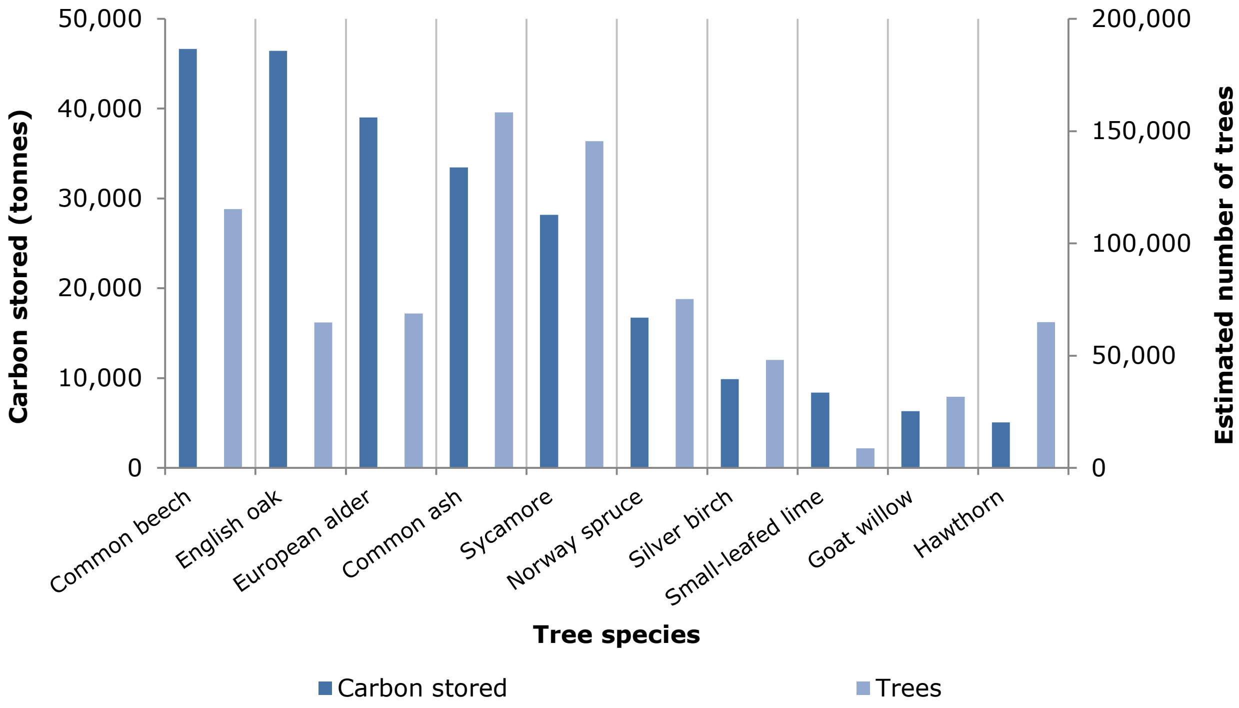


Figure 15. Amount of carbon stored in the ten species with the highest storage rates and the frequencies estimated by i-Tree Eco.

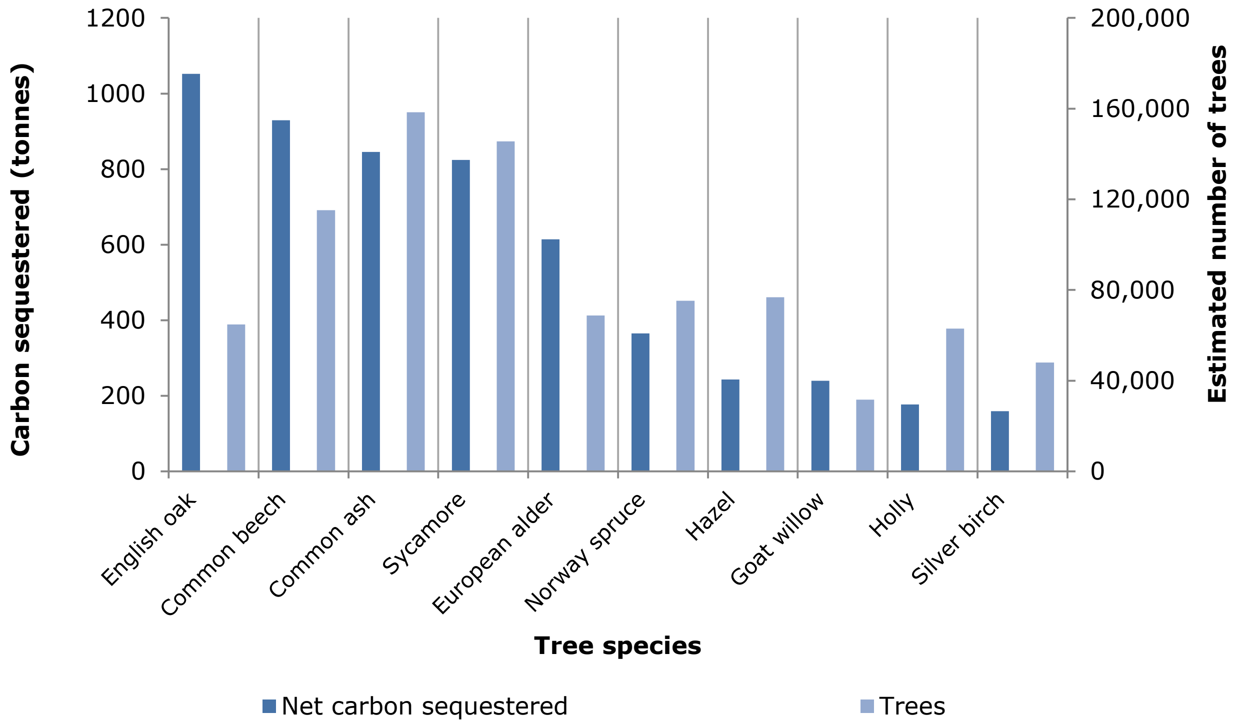


Figure 16. Carbon sequestered per year by the ten trees with highest rates, along with the species frequencies estimated by i-Tree Eco.

Carbon storage and sequestration

The role of carbon in climate change is often cited as instrumental. This is because the temperature of the Earth depends upon a balance between incoming energy from the sun and that returning to space. Carbon dioxide (CO_2) absorbs heat that would otherwise be lost to space. Some of this energy is re-emitted back to Earth causing additional warming. The urban forest is 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.

This i-Tree Eco study shows that for the urban forest of Cardiff there is an over reliance on beech and oak for sequestering and storing carbon. There is a risk in two species contributing so much as it increases vulnerability to pests and diseases and produces the potential for large emissions of carbon when the trees decompose.

Future planting of a greater diversity of trees whose capacity and form is to grow over 10 meters in height and have large leaves or otherwise dense evergreen foliage should feature within Cardiff's urban forest. This is because these species have the capacity to store large quantities of carbon over the long-term. Additionally, pioneer species, which tend to be quick growing, will have a positive impact on carbon storage in the short-term. Such trees include: tulip tree, silver maple, oak, hickory, red mulberry, dogwood (*Cornus mas*), blue spruce, pines, *Liquidambar* (American sweetgum), *Ostrya*, *Pterocarrya* and *Zelkova*, where suited to the location. UK pioneers including silver birch and willow are worth a mention too.

Habitat Provision

The issue

The UK is suffering from a net loss of biodiversity and - in Wales - a third of the assessed priority species are in decline (Hayhow et al., 2016). Supporting nature in cities helps to conserve wildlife species and retain opportunities for people to view and interact with nature. This connection to nature is linked to improved health and wellbeing (Sandifer et al., 2015) and understanding of the natural world (Miller, 2005). Cardiff hosts a number of protected species associated with trees, including bats, dormouse, barn owl, warblers, and butterflies (CCC, 2017b).

How trees can help

Trees create habitats which other flora and fauna use (Smith et al., 2006; Nielsen et al., 2014). Native trees have been thought to be more important in supporting native biodiversity (Kendle & Rose, 2000), but non-natives can also be beneficial for nature, particularly in urban areas where native trees may not always be suitable (Sjöman et al., 2016). In particular, non-native species can be important food sources for pollinators (Baldock et al., 2015). Larger and older trees have been found to harbour greater biodiversity (Nielsen et al., 2014; Carr et al., 2018). Overall, a diversity of trees is most important, with a range of tree species, ages and sizes offering the greatest range of possible habitats (Nielsen et al., 2014).

Cardiff's trees

Cardiff's urban forest contains a large number of tree species, 56% of which are native trees. This includes rare native species: black poplar and elms (Cottrell, 2004; Tomlinson & Potter, 2010). Many of Cardiff's woodlands are also recognised as nationally important, with four woodland SSSIs and a SAC[11] designated for Cardiff's Beech Woodlands. A number of trees in Cardiff were also found as part of hedgerows and parkland, which are listed as section 7 priority habitats under the Environment Act (2016).

The biodiversity value of Cardiff's trees was assessed using data on a range of biodiversity value of trees. This analysis provides an indicator of the relative value of tree species and their population size in Cardiff. High populations of trees which have low biodiversity value may indicate opportunities for changes in the composition of the urban forest to improve its value to wildlife.

In their review, Alexander et al. (2006) scored trees from high value (5) to low value (0) for supporting fungi and epiphytes, providing pollen and nectar, fruits and seeds. The biodiversity value of Cardiff's urban tree population is assessed by reviewing the biodiversity value of the tree species and their population size in Cardiff. Information on the number of invertebrates associated with tree species was gathered from Southwood (1961), Kennedy and Southwood (1981), supplemented for additional species from the BRC (BRC, 2018). While these values provide a useful indicator of the relative biodiversity value of different trees, it is important to note that these values are gathered from various sources using different methods and from different locations, and in particular are not specific to trees in urban areas.

Biodiversity values were assessed for six aspects of biodiversity, three of which were selected to be shown here: foliage invertebrate richness, blossom and pollen provision, and seed and nut provision (Figures 17-19). The remaining biodiversity values are provided in Appendix IV. The figures illustrate the values of different species, but generally show that many of Cardiff's larger tree populations provide high levels of biodiversity value. It also identifies potential species for future planting which could be considered to provide biodiversity value.

[11] SSSI: Site of Special Scientific Interest designated for Wildlife and Geology under the Wildlife and Countryside Act (1981) as amended.
SAC: Special Area of Conservation. Designated for priority habitats and species under the European Commission Habitats Directive.

Table 8. Tree species encountered in Cardiff that are beneficial to pollinators

Species	Season
Apple, common	Spring
Cherry laurel	Spring
Field maple	Spring
Goat willow	Spring
Horse chestnut	Spring
Sweet cherry	Spring
Norway maple	Spring
Hawthorn	Summer
Holly	Spring, summer
Bay laurel	Spring
Sycamore	Spring
Lime, small-leafed	Summer
Lime, large-leafed	Summer
Rowan	Summer
Strawberry tree	Autumn

Habitat provision by urban trees

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

Figure 17. Tree species ranked by the number of foliage invertebrate species they support. The graph shows that Cardiff's sizeable populations of willows, oaks and birches support the greatest species richness. Non-native species, of which sycamore is one of Cardiff's dominant species, tend to be support fewer associations with foliage invertebrates than native species. However, some non-natives can perform well and be important surrogate species when natives go into decline, such as sycamore and horse-chestnut when elms were lost to dutch elm disease (Key 1995; Alexander et al., 2006). Conversely some native species associate with few species, such as yew which has high defences against invertebrate foragers.

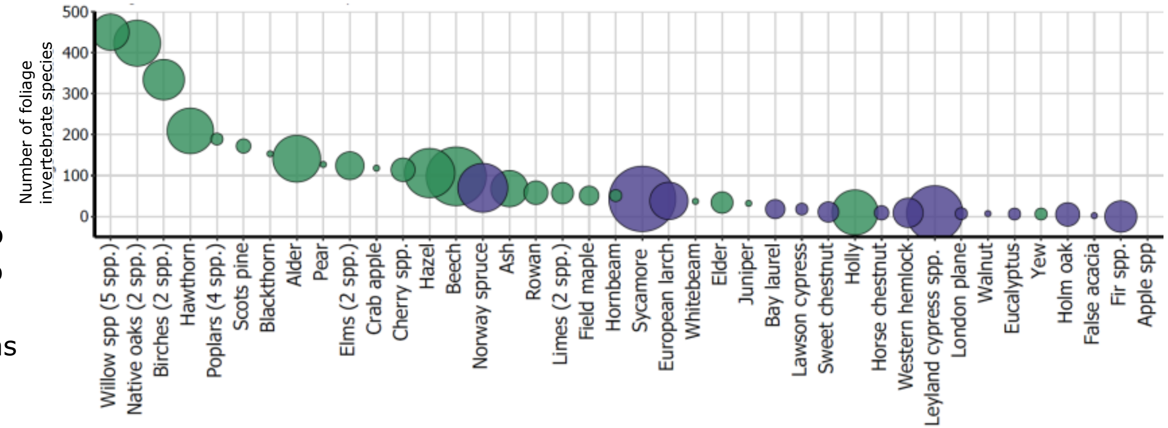


Figure 18. Tree species ranked from 0 to 5 for their provision of pollen and nectar. Native species of willow, hawthorn and holly are ranked highest, though many non-native species also perform well. Trees can be important sources of food for pollinating invertebrates (Alexander et al., 2006), which are themselves in decline (Baldock et al., 2015). Diversity in trees which produce pollen and nectar are also important – trees come into flower at varying times of year from spring to autumn, and having a constant source of pollen and nectar available helps to support pollinator species. Table 9 provides a review of tree species and their flowering times.

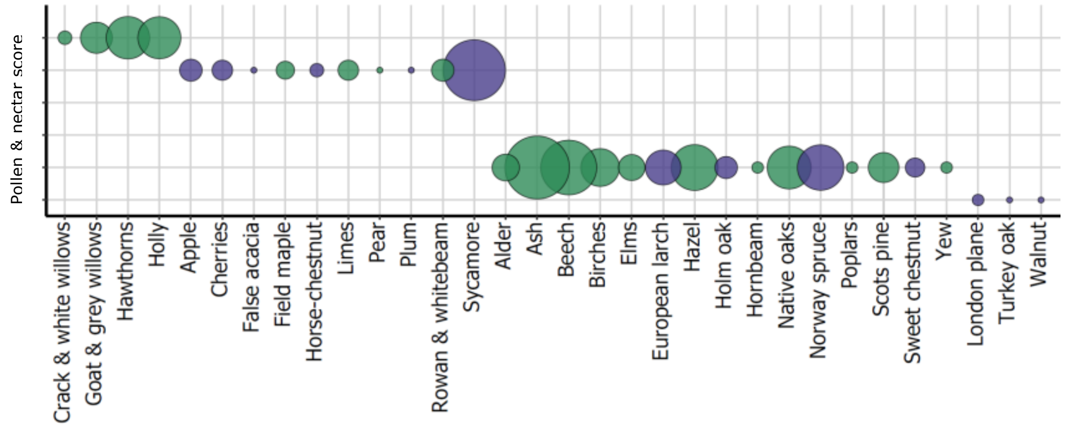
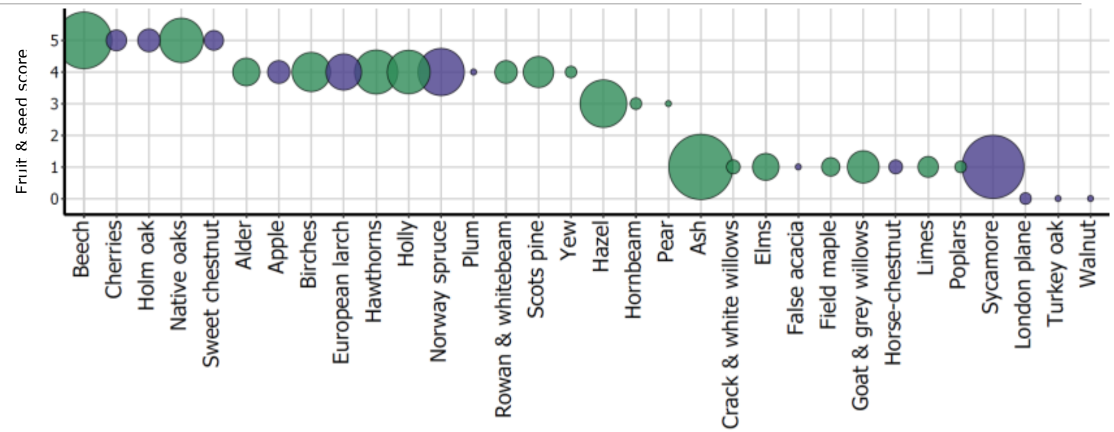
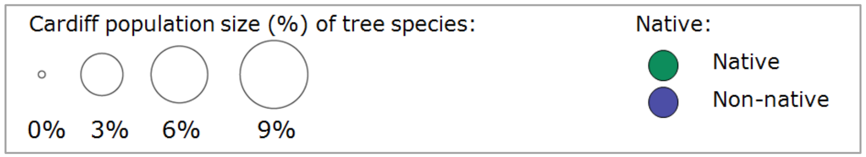


Figure 19. Tree species ranked for the provision of fruits and seeds, which can support a range of invertebrates, birds and mammals. A mix of woodland, orchard, native and non-native species are found to be most valuable here.





Replacement Cost and Amenity Value

CTLA valuation

The urban forest of Cardiff has an estimated **replacement value of £309 million** according to the CTLA Apraisers, (1992) valuation method. This is the cost of replacing the urban forest of Cardiff should it be lost; this valuation method does not take into account the health or amenity value of trees, only the trunk area.

CAVAT valuation

The urban forest of Cardiff has an estimated **public amenity asset value of £11.2 billion** according to CAVAT Quick Method valuation (Doick et al., 2018), taking into account the size and health of trees as well as their public amenity value. The English oaks trees in Cardiff had the highest overall value (Table 9, Figure 20), representing 6% of the total public amenity value of all of trees in Cardiff's urban forest. This is because most oaks were mature ones. Large, healthy long lived trees provide the greatest structural and functional value, which translates into the greatest amenity values.

The single most valuable tree encountered in the study was a common beech, estimated to have a CAVAT asset value of £95,554.

The land use type containing the highest CAVAT value of trees is 'agriculture', with 37% of the total value of the trees and estimated value of approximately £2 million. This equates to greater than £4 billion when extrapolated for the whole of Cardiff. Vacant land and parks were also important contributors for the CAVAT value (Figure 21). In i-Tree Eco studies and pan-city CAVAT valuation studies, trees on these land-use types typically return a high contribution to total public amenity.

Table 9. CAVAT value for the main genera.

Genus	Value of measured trees	Total value across Cardiff
Quercus	770,160	1.36 billion
Fraxinus	740,730	1.31 billion
Alnus	738,146	1.3 billion
Acer	736,634	1.3 billion
Fagus	637,497	1.1 billion
Picea	360,519	637 million
Larix	223,830	395 million
Cupressocyparis	211,691	374 million
Thuja	205,546	363 million
Salix	185,055	327 million

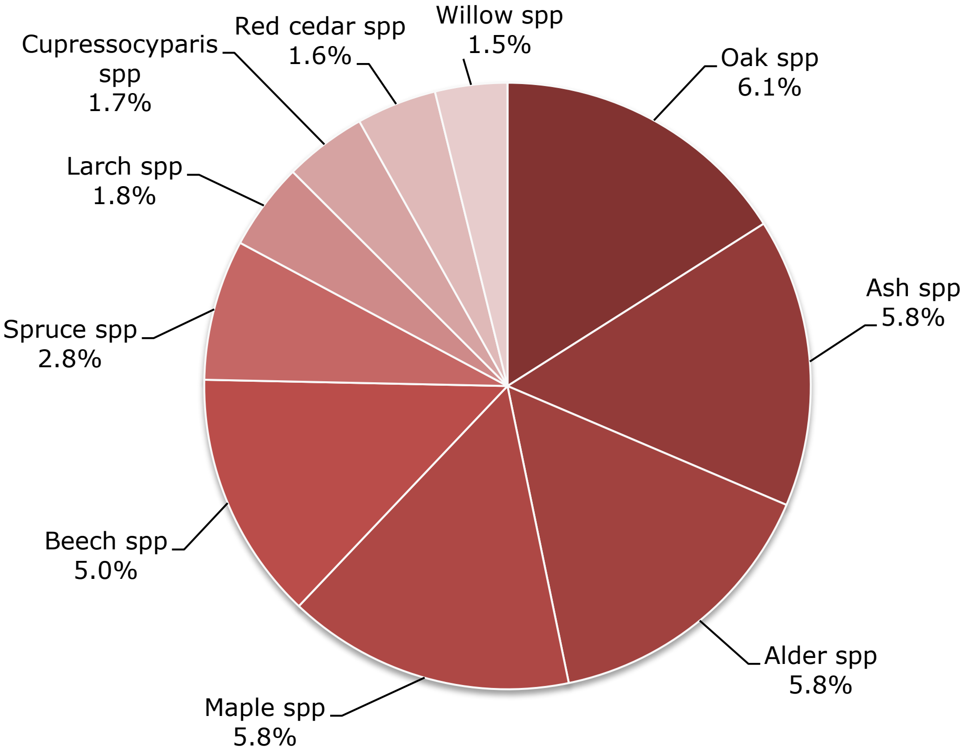


Figure 20. Ranking of the top-ten tree species according to their CAVAT valuation.

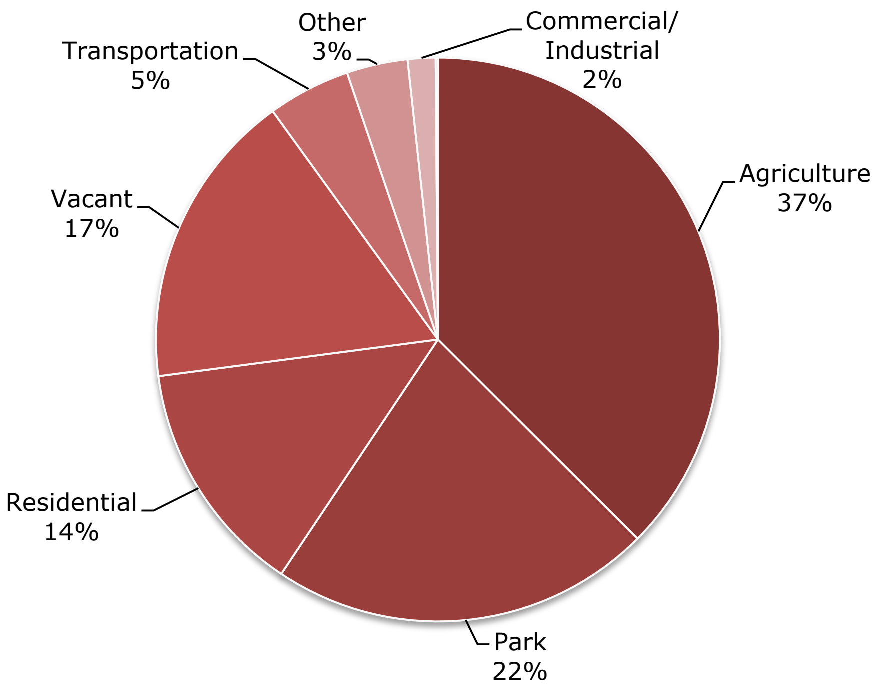


Figure 21. Percentage of the public amenity value held by trees in Cardiff according to land use.

Valuing amenity trees

CAVAT provides a method for managing trees as public assets rather than liabilities. It is designed not only to be a strategic tool and aid to decision-making in relation to the tree stock as a whole, but also to be applicable to individual cases where the value of a single tree needs to be expressed in monetary terms. In this evaluation the CAVAT Quick Method was used.

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.

Agricultural land, residential, vacant land and parks were the land use types across Cardiff with the greatest CAVAT value. By conserving maturing large stature trees in publicly accessible places such as parks will help to ensure that the urban forest has high public amenity into the future. 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.

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 since its arrival in the 1960s (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. 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 Cardiff on a single genus (Table 10) and for multiple genera (Table 11).

With increased importation of wood and trees, in addition to a climate that is becoming more vulnerable to many pests and diseases, ensuring urban forests are resilient is of paramount importance.

Protecting the urban forest as a whole against threats can be helped by increasing the diversity of tree species across Cardiff. Pests and diseases not currently 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.

Table 10. Risk matrix used for the probability of a pest or disease becoming prevalent in the Cardiff 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 South Wales			

Table 11. Risk matrix used for the probability of a pest or disease becoming prevalent in the Cardiff urban forest on multiple genera.

Prevalence	% Population		
	0-25	26-50	>50
Not in UK			
Present in UK			
Present in South Wales			

Healthy trees

Ash dieback caused by Chalara has raised serious concerns about the health of our trees and woodland. A combination of climate change and the accidental and deliberate introduction of non-native species pose a threat to many UK trees through increased incidence of pests and diseases – increasing the importance of managing the existing tree stock and planting new trees that will increase the resilience and robustness of woodland and greenspaces. Local Authorities can review their tree inventory to identify where these may be under threat now or into the future.

Ensuring a diverse range of species and ages of trees can help increase resilience both to attack by pests and diseases and to the extremes in weather forecast under a changing climate. Advice is available on suitable species for projected climate change in your area from www.righttrees4cc.org.uk and http://www.tdag.org.uk/species-selection-for-green-infrastructure.html.

Table 12 gives an overview of the current and emerging pests and diseases that could affect Cardiff'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 III – Pests and Diseases. The tables present the population of the urban forest of Cardiff 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. The information contained in the tables can be used to inform programmes to monitor the presence and spread of a pest or disease, and strategies to manage the risks that they pose.

Table 12. Risks of emerging pests and diseases

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in South Wales	Risk of spreading to South Wales	Population at risk (%)	CAVAT value of trees (£)	Stored carbon value trees (£)
Acute oak decline	*Quercus robur, Q. petraea*	SE England and Midlands	Confirmed cases on the Welsh/English border	High – already present	**4.72%**	1.3 billion	11.5 million
Asian longhorn beetle	Many broadleaf species (see Appendix IV)	None (previous outbreaks contained)	None	Medium risk – climate may be suitable	**58.27%**	6.4 billion	47.4 million
Chalara dieback of ash	*Fraxinus excelsior, F. angustifolia*	Cases across the UK	9 confirmed cases in Wales	High - already present	**11.48%**	1.3 billion	8.2 million
Emerald ash borer	*F. excelsior, F. angustifolia*	None	None	Medium risk (imported wood)	**11.48%**	1.3 billion	8.2 million
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	**16.96%**	2.7 billion	13 million
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	**19.42%**	3 billion	27.2 million

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in South Wales	Risk of spreading to South Wales	Population at risk (%)	CAVAT value of sampled trees (£)	Stored carbon value trees(£)
Oak processionary moth	*Quercus* spp.	Three sites in S England	None	Medium, small colonies are containable	**5.78%**	1.36 billion	11.8 million
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	Many cases in S. Wales	High – already present	**12.7%**	1.52 billion	13.4 million
Phytophthora kernoviae	*F. sylvatica, Ilex aquifolium, Q. robur, Q. ilex*	Mainly SW England and Wales	Five locations in S. Wales	High – already present	**18.29%**	2.6 billion	23.2 million
Phytophthora alni	*Alnus* spp.	Riparian ecosystems in the UK	Heavy losses in parts of Wales	High – already present	**7.74%**	1.3 billion	11 million
Dothistroma (red band) needle blight	*Pinus nigra ssp. laricio, P. contorta var. latifolia, Pinus sylvestris*	Several UK sites	Found in 3 out of 4 forest districts in Wales	High – already present	**0.25%**	204 million	1.2 million
Spruce bark beetle	*Picea* spp.	Mainly W England and Wales	Established in Wales	High – already present	**5.58%**	637 million	4.1 million

ǂ Other tree species are also affected, one of which was found in Cardiff: Cherry laurel (*Prunus laurocerasus*).

Stratification

Neighbourhood Areas

To aid local interpretation of the Cardiff's i-Tree Eco data and designing actions arising from the study's findings, survey data was organised into two blocks (post-stratified). These were defined using the Cardiff Liveable City Report, which defined six neighbourhood areas (CCC, 2017a). The six neighbourhoods were combined to give two sections: North (Cardiff West and Cardiff North), and South (Cardiff South West, Cardiff City and South, Cardiff South East, and Cardiff East; Figure 22).

The North section of Cardiff contained much of the more rural area of the city, including large tracts of agriculture and woodland. In contrast, the South section contained more built-up areas of the city and had about twice the population density of the North. Published well-being assessments of the neighbourhoods have identified several differences in demographics, socio-economics and residents' satisfaction with health and the environment (CCC, 2017a). Some of these differences are listed in Figure 22.

The stratification applied allowed for a quantification of some of the ecosystem services provided by the trees located in the two areas, and their amenity value. These differences are listed in Table 13.

Due to its larger area and more rural make-up, the North section holds the majority of Cardiff's trees. The population of the North block therefore receives greater ecosystem services from avoided runoff, carbon storage and sequestration and air pollution removal. Most of the trees in the North block were in private ownership, though a relatively large proportion were found in parks. In comparison, the South contained many more trees in public ownership, such as street trees. In both the North and South blocks, ash was the most common species, highlighting a keen vulnerability across the city from Chalara ash dieback.

However, it must be noted that as this stratification was applied post-survey, the numbers of plots in each block were not equal and therefore the values are indicative, only.

	Socio-economics	Urban forest
North	▪ Generally high life expectancy, feeling of safety and agreement that Cardiff is a clean, attractive place to live ▪ High use of cars for commuting ▪ 13,450 homes to be built by 2026 ▪ 75.9 ha of open space to be developed	▪ High tree density ▪ More trees in private ownership - agriculture ▪ Dominated by ash and beech ▪ High ecosystem service provision
South	▪ High levels of deprivation and high concern with standard of living ▪ Low life expectancy and low satisfaction with health ▪ Low satisfaction with public services ▪ 2,500 homes to be built by 2026 ▪ 1.2 ha open space to be developed	▪ Low tree density ▪ Few large trees (>40 cm DBH) ▪ Dominated by Leyland cypress and ash ▪ More trees in public ownership – street trees ▪ High proportion of trees in residential areas ▪ Low ecosystem service provision, but more people that could benefit from the local air pollution and amenity services

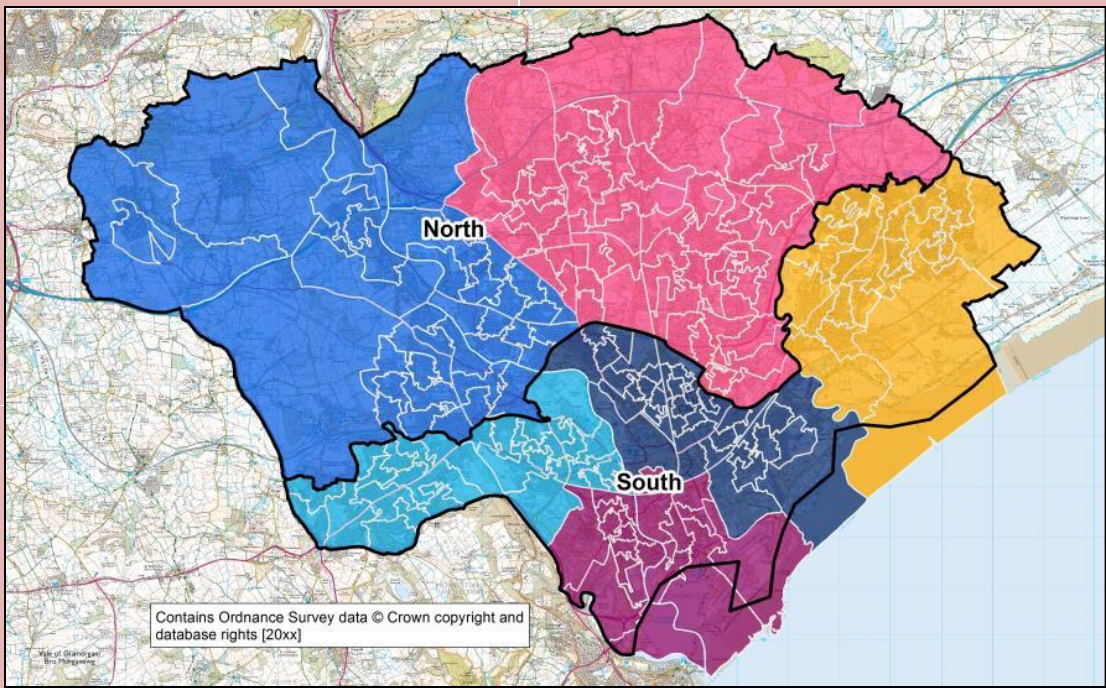


Figure 22. Summary of differences in the social, economic context of the North and South sections of the city with the differences in the size and composition of the urban forest in the two areas. The boundaries of both the North and South areas used for the stratification are shown as the black lines (with some area of the South neighbourhoods excluded to fit the i-Tree Eco study boundary selected in the methodology). The coloured areas delineate the six neighbourhoods defined with Cardiff's Liveable City Report (CCC, 2017a).

Table 13. Headline figures for North and South areas of Cardiff.

	North	South
Total number of trees (estimated)	1,237,800	172,300
Trees per ha	136	35
Total leaf area (estimated ha)	11,300	1,300
Canopy cover (%)	25.3%	7.3%
Top three most common species surveyed	Common ash (11%) Sycamore (11%) Common beech (9%)	Leyland cypress (14%) Common ash (11%) European aspen (9%)
Number of species	58	31
Trees in public ownership	27%	45%
Top three land uses where a greater % of trees were found	Agriculture (39%) Park (25%) Vacant (15%)	Residential (40%) Transport (35%) Park (13%)
Proportion of surveyed trees of different sizes (by dbh)	7-20 cm (41%) 20-40 cm (37%) 40-60 cm (14%) 60+ cm (7%)	7-20 cm (55%) 20-40 cm (32%) 40-60 cm (10%) 60+ cm (3%)
Avoided runoff (m^3 per year)	319,400	36,400
Air pollution removal (t per year)	157	33
Carbon storage (tonnes to date)	299,500	21,600
Net carbon sequestration (tonnes per year)	6,900	1,000
Amenity value (CAVAT)	£8 billion[1]	£1 billion[1]

[1]Values don't match with the total evaluation as once populations are divided between North and South, the CAVAT methodology assumes that trees from the North area (with fewer residents) are no longer visible to a large population.

Council Ownership

The canopy cover and composition of the urban forest within land managed by the City of Cardiff Council was examined. This used both NRW's (2016b) canopy cover maps and a review of composition of trees within the i-Tree Eco plots located in the ownership area (Figure 23). Council-owned trees can differ from publicly owned trees assessed previously (within the Species Composition section), as it may exclude trees in areas owned by other public bodies and include land-uses not normally assumed to be open to the public, such as residential areas maintained by the council.

The canopy cover within Council owned land totalled 869 ha (Table 14). The percentage of canopy cover for council-owned land is 25.7%, higher than that estimated for Cardiff as a whole. From this it is estimated that City of Cardiff Council maintains 32% of the canopy cover in the study area. It is also estimated that 30% of all Cardiff's trees are in Council ownership. This estimate however may be underestimated due to the fact that trees on most streets were not considered in this, and that the NRW (2016b) canopy cover map does not include all trees in some of the more rural areas within the study boundary.

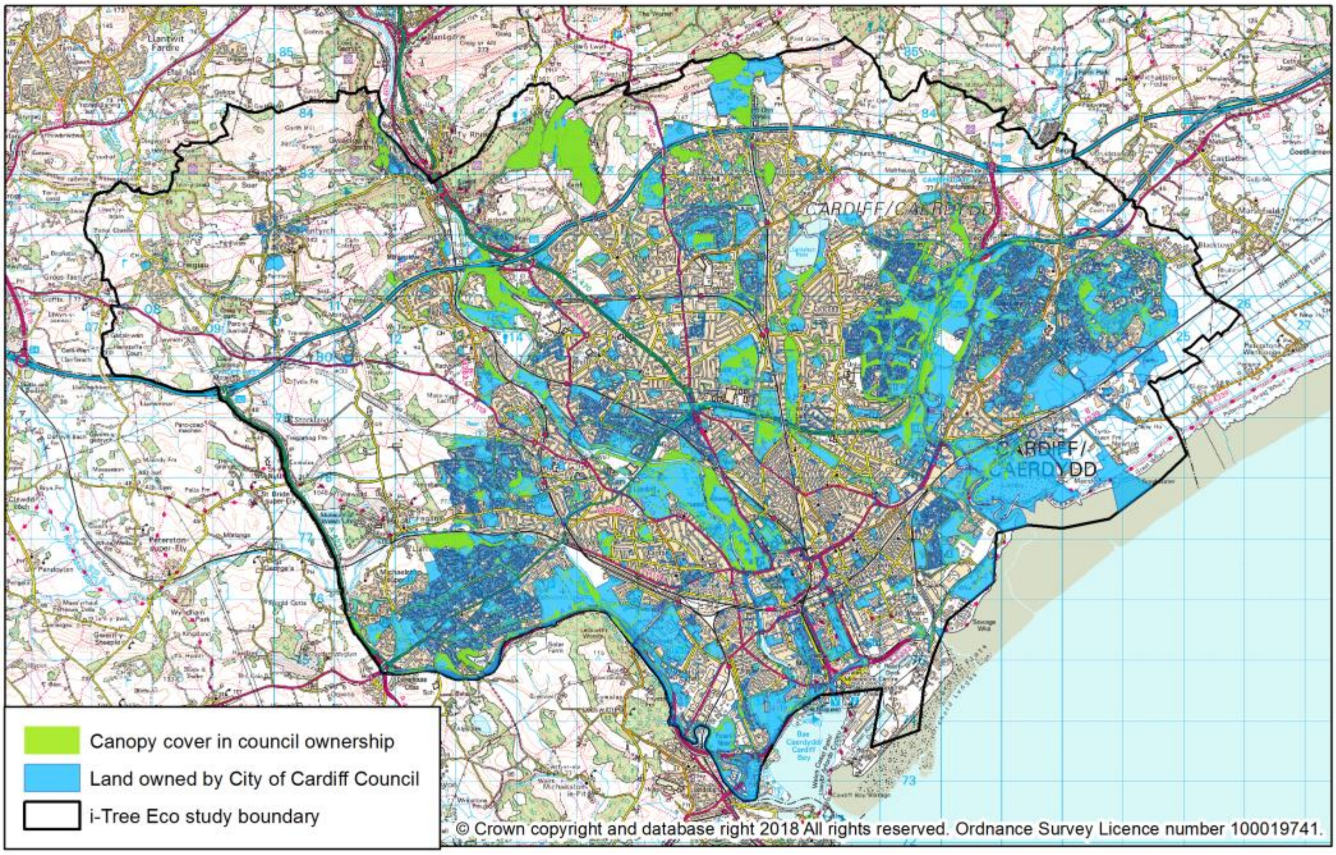


Figure 23. Map of land owned by the City of Cardiff Council and canopy cover within this area. Canopy cover data from NRW (2016b).

A total of 63 plots were located within, or partially within, council-owned land (22% of all plots). 18 of these plots contained trees. The composition and structure of these trees was reviewed (Table 14). It must be stressed that due to the small number of plots found in council ownership that the values should be interpreted with care.

The majority of council-owned tree were found in one of three land-uses: Transport, Park or Residential. The size distribution of trees was poorer than that found for Cardiff in general, with the majority of trees having a DBH under 20cm and fewer trees found in the over 60 cm category than the recommended 10%. All of the trees over 60 cm DBH were found in parks, with the exception of one tree found in residential.

Table 14. Review of canopy cover estimates and composition of urban forest within City of Cardiff Council ownership. Total area of canopy cover estimated from NRW's (2016b) canopy cover map.

	Council owned land
Area (ha)	3,378
Canopy cover (ha) (Percentage of Cardiff's total canopy cover)	868 (32.6%)
Percentage canopy cover on council land	25.7%
Top three most common species surveyed	Leyland cypress (17.3%) Common ash (14.3%) European aspen (8.2%)
Percentage of trees native species	54.1%
Number of species	25
Top three land uses with greatest % of trees found	Transport (34.8%) Park (33.7%) Residential (23.6%)
Proportion of surveyed trees of different sizes (by dbh)	7-20 cm (57.1%) 20-40 cm (25.5%) 40-60 cm (11.2%) 60+ cm (6.1%)

Natural Capital Account

Natural Capital (NC) is defined as *"the elements of nature that directly and indirectly produce value or benefits to people, including ecosystems, species, fresh-water, land, minerals, the air and oceans, as well as natural processes and functions"* (NCC, 2014). **Natural Capital Accounting (NCA)** is a methodology for calculating the state of natural capital asset(s) and the flow of ecosystem services they produce, with the aim to inform decision-making.

NCA is a broader approach than the valuation of services conducted in the previous sections as it takes a long-term focus to measuring the value of natural assets. It is also explicit in linking the quantity and quality of natural capital to the flow of services and benefit value it produces, making it a useful management tool for tracking change in natural assets and their values. Finally, NCA helps present metrics and values of the environment in an accountancy framework allowing it to be reviewed in relation to other capital accounts.

NCA has grown in use in the UK, which has a strong history in environmental valuation stemming from being the first country to produce its own environmental accounts (UK NEA, 2011). The UK is pushing to track all environmental assets, with the ONS and DEFRA leading the work and following NCA principles to produce an urban environment account by 2020 (ONS, 2017; 2018a) with initial estimates published (ONS, 2018b). Both rural forests and urban greenspaces have been areas of key interest for environmental valuation. The urban forest estate of England was valued at £748 billion (gross), with recreation alone worth £14.9 billion. London's urban greenspaces were recently valued at £91 billion (gross) with every £1 invested bringing £27 worth of benefits (Vivid Economics, 2017). These studies demonstrate the financial value of these spaces, **though often only measuring a subset of all ecosystem services** and are therefore an under-estimation. Many of these benefits are external values, i.e. their benefit is to society, rather than their owners or managers. While NC can provide private value, which is returned to their owner or manager, this may be small in relation to the management costs. For example, **in Forest Enterprise's (2017) NC account annual management costs were nearly twic e the private benefit, but many times smaller than the external value to society.** NCA helps to capture these external values and make their value and dependence on healthy environments to deliver them explicit in decision-making.

Not all ecosystem services have an evidence base sufficiently robust to allow them to be quantified and valued in an NC account. Further, some benefits of the environment should arguably never be valued as monetary values are not an accurate measure of their worth, such as intrinsic value for nature (McCauley, 2006). Therefore, NC accounts provide only a subset of the true value of environments and do not represent a 'price' for nature.

Natural Capital Methodology

A natural capital account breaks down the provision and valuation of services into a series of steps involving:

1. Quantifying the state of the natural capital asset (Stock assessment),

2. Calculating the provision of services that flow from it and the economic value of the services (Flow and monetary accounts), and

3. Calculating the present value of these services (Summary account).

A number of services were identified that could be of high value to Cardiff and its residents (Table 1). While four of these services could be valued using i-Tree Eco, other services and their values could not, and therefore are not considered further in this account.

These steps are here described below, using three tables.

- **Table 15: Stock assessment**
  - The stock assessment tracks the current quantity and state of the natural capital asset – in this case, Cardiff's urban forest. The urban forest has been split into 'public' or 'private' trees, and in each case sub-divided by land-use. Indicators to measure and track change, where possible, are also listed.

- **Table 16: Flow and monetary accounts.**
  - These accounts first measure the quantity (or 'flow') of ecosystem services which are derived from the account. The estimated value of these services is then calculated. Finally, Present Values (PV) were calculated to capture the value of the provision of ecosystem service benefits by the urban forest over the next 100 years. This assumes there is no change in the composition, structure or size of the urban forest over this time. The PV is discounted to account for the fact that value of services in today's term is worth less the further into the future you go, for which the HM Treasury's green book discount rates (2018) were applied (0-30 years = 3.5%, 31-75 years = 3%).

- **Table 17: Summary account**
  - Provides the total PV for annual ecosystem services which represents the asset value of Cardiff's urban forest over the next 100 years.

Table 15. Stock assessment of Cardiff's urban forest subsets, in land-use categories in private or public ownership. The top row lists key indicators which track the quantity and quality of Cardiff's urban forest. The bottom section of the table links these indicators to key ecosystem service delivery and other indicators of urban forest health. The colours identify trends and source of trends of increase (green) or decline (red). Lack of information on trends in Cardiff's urban forest mean trends cannot be assigned to most changes (blue = no info).

Urban forest units:		Est. number of trees (per ha)	Est. canopy cover	Number of species	Most dominant species percentage (species)	Condition (% excellent or good)	% large tree (>60cm)
Urban forest		1,410,000 (100)[12]	19%[14]	73	11% (Ash)	75	28,000[14]
Public trees		421,000 (109)	13%	34	19% (Ash)	75	26,000
	Transport	84,000 (36)	5%	13	23% (Ash)	75	2,000
	Park & cemetery	336,000 (227)	31%	26	18% (Ash)	83	26,000
Private trees		989,000 (97)	14%	58	9% (Sycamore)	75	69,000
	Agriculture & woodland	481,000 (149)	26%	22	15% (Sycamore)	77	33,000
	Residential	241,000 (77)	8%	41	36% (Leyland cypress)	86	11,000
	Commercial	19,000 (15)	3%	2	82% (European alder)	91	0
	Vacant	192,000 (169)	24%	21	15% (European alder)	72	21,000
	Other (institutional, other, golf course, water/wetland, utility)	56,000 (39)	7%	9	50% (Holly)	88	4,000
Indicator for							
Pest & disease resilience				x	x	x	
Ecosystem Service delivery		x	x			x	x
Tree diversity				x	x		x
Amenity value			x	x	x	x	x

[12] NRW 2016

Table 16. Flow account and monetary account for Cardiff's urban forest. The flow account tracks the quantity of ecosystem services being produced from the urban forest, and the economic value of this ecosystem service provision, incorporating the fact that the value of a service may change with time. For example, carbon storage and sequestration increase as the annual value of a tonne of carbon increases year upon year. In the final column the annual value of services is converted into a Present value, representing the value of that ecosystem service provision for the next 100 years.

	Flow account			**Monetary account**			**Present value**
	Stock / Flow	Flow units	Trend in flow	Unit value	Trend in unit value (source)	Economic value	100 year value (discounted)
Carbon storage	321,000	Tonnes	Static*	3.67 tCO_2e = £238 (2017)	Increasing (DBEIS, 2018)	=£76.6 million	£76.6 million*
Net carbon sequestration	7,949	Tonnes per year	Static*	1 tonne carbon = 3.67 tCO_2e = £238 (2017)	Increasing (DBEIS, 2018)	=£1.9 million per year	£1.9 million**
Air pollution removal	NO_x = 37.9 SO_x = 8 $PM_{2.5}$ = 13.7	Tonnes per year	Static*	1 kg NO_x = £12.205, 1 kg SO_x = £1.956 1 kg $PM_{2.5}$ = £33.713	Static (UKSDC from DEFRA, 2015b)	= 940,000 per year	£28.1 million
Avoided runoff	355,900	m^3 per year	Static*	1 m^3 = £1.34 avoided sewerage costs	Static (Welsh Water, 2017)	= £477,000 per year	£14.2million

* Cardiff's urban forest is considered to be static based on the stock assessment. While the number of trees is increasing, canopy cover appears to be in decline. Without further information on trends, the forest is assumed to remain static for the duration of the account.

** Assuming the urban forest remains static for the next 100 years, carbon sequestration at its current rate would be valued at over £100 million. However, this implies the forest is growing and therefore not static as assumed here. Without information on likely future trends in the urban forest and its management, carbon sequestration over the next 100 years will be assumed to be zero.

Table 17. The total annual value of ecosystem service provision by services Cardiff's urban forest and the 100 year Present Value (PV) of these services. The Net Present Value (NPV) is the discounted value of benefits over the next 100 years minus the discounted costs over the next 100 years.

	Total
Annual costs*	£550,000
Annual benefits (avoided runoff, air pollution removal, carbon sequestration)	£3.31 million
Annual net value (benefits minus costs)	£2.76 million
Benefit : Cost ratio	£6:1
100 yr Present Value (PV) (avoided runoff & air pollution removal, discounted)	£44.2 million
100 yr Net Present Value (NPV) (avoided runoff & air pollution removal minus costs, discounted)	£27.8 million

*This value represents the maintenance budget for the City of Cardiff Council Arboricultural Team for maintaining trees in streets, estates and parks, as well as the Park team's maintenance of woodland trees.

Natural Capital Account Results

The PV calculated for Cardiff's urban forest of £44.2 million reflects a small proportion of the total value of the urban forest (Table 17). This value is estimated from only two of the many ecosystem services urban forests can provide. This value also assumes no change in the urban forest over the next 100 years. This is unrealistic, with trends suggesting a decline in urban forest cover (NRW, 2016a) and continued development pressure in Cardiff. The future benefit provision in Cardiff will depend both on the demand for services from those who live, work and visit Cardiff, but also by how the urban forest will change in the next 100 years.

The growing population of Cardiff is likely to increase the number of individuals benefiting from existing and future urban trees, such as benefitting from reduced air pollution, more attractive areas for recreation, socialising and relaxation. Additionally, the value of carbon storage in Cardiff's is likely to increase with the increasing value of carbon (DBEIS, 2017) as climate change becomes an ever more significant threat.

How the urban forest is managed today and in the future will affect whether current rates of annual benefit provision can be maintained or increased in future years. Ecosystem service delivery depends not only on tree planting and removal, but also which species are planted and where and whether they are maintained in a healthy condition and able to reach maturity, when their ES provision are expected to be greatest.

The management costs borne by City of Cardiff Council are £550,000 annually. These costs maintain an asset worth £11 billion providing over £3.3 million annually (Table 17). This valuation of the urban forest only captures a portion of its total value to people who live, work and visit Cardiff.

Many services were not able to be valued and included in this calculation. Carbon sequestration values could not be included in the final PV and NPV calculations due to uncertainty on the future management of the urban forest.

Assuming the carbon sequestration rate was to remain static, the PV for this service would be nearly £150 million on its own. However, the maintenance of this sequestration rate would require substantial levels of tree planting to expand the total carbon storage capacity of the urban forest. If no further planting was undertaken the carbon sequestration rate would slow and decline as trees reach maturity when sequestration rates slow.

Conclusions

Cardiff's urban forest is estimated to contain over **1.4 million trees**. A total of 73 species were identified in the survey. The three most common species are ash *(Fraxinus excelsior*), sycamore (*Acer pseudo-platanus*) and beech (*Fagus sylvatica*). Beech is considered to be the most dominant species, with the greatest combined leaf area and frequency.

Cardiff's urban forest provides services valued at **£3.31 million per annum**. This valuation only considers ecosystem services of carbon sequestration, air pollution removal and avoided stormwater runoff and does not include, for example, benefits to health, social and cultural values, amenity value, and wildlife value. These services can help Cardiff towards its goals of reducing greenhouse gas emissions and improving the health of its residents, by improving air quality and mitigating the risk of damage from flooding from stormwater runoff.

Cardiff's canopy cover was estimated at 18.9%. This is higher than many other cities in the UK which have been assessed, and is especially good as Cardiff is a 'coastal city' which tend to have lower canopy cover (Doick et al., 2017). Out of the 312 towns and cities on the www.urbantreecover.org website, Cardiff would be placed 101st out of the 312 locations. However, the boundary used here for Cardiff included large areas of 'rural' space including woodlands and agriculture. NRW's (2016a) estimate of 15.4% canopy cover in 2013 reflects the area within the built, urban environment and may be more comparative to other cities who used a similar urban extent boundary for their i-Tree Eco studies. For instance, 15.4% tree cover is similar to Leicester and Nottingham (15.2%).

In 2016, NRW estimated that over 3000 ha across Cardiff was potentially available for tree planting (NRW, 2016a). Not all of this space could realistically be planted, but this does indicate that opportunities for planting in urban areas are present. Development areas, particularly in the northern region of the city where tree cover is higher, could see a decline in canopy cover if urban expansion is not managed and mitigated with respect to canopy cover.

Cardiff's tree population is slightly under-populated by large trees which provide the greatest ecosystem service values. **6.9%** of Cardiff's trees are estimated to be over 60 cm in trunk diameter. These large trees provide the greatest ecosystem service value as well as potentially forming iconic heritage features in urban areas. However, a report by NRW (2016b) found a declining trend in large stature trees in Cardiff, and Wales generally. This study also found a significant bias towards young, smaller trees, with 79.5% of trees inventoried with a stem diameter less than 40 cm.

Two species were dominant in Cardiff: ash and sycamore. More than one in five trees in Cardiff belongs to one of these two species. High proportions of single species can be a vulnerability in the urban forest as a decline in one of these species represents a significant loss of canopy cover and ecosystem service delivery. For example, the replacement value of ash based on its amenity value is £1.3 billion. The potential impact of **chalara ash dieback** could therefore have a very significant impact on the amenity value of Cardiff's urban forest.

Increasing species diversity could increase resilience to pest and diseases, improve ability of the urban forest to adapt to climate change, and provide a range of habitats for wildlife. The habitat analysis indicated a number of native smaller tree species (cherries, apple and pear) which could be used to support pollinators and could provide local food as part of urban orchards.

The North section of the study area holds **86%** of Cardiff's trees. Most of these trees were found in agricultural and wooded landscapes. The current high canopy cover of the north section **(25%)** may be at risk from development areas planned for **808 ha (or 9%)** within the North section.

The South section receives approximately 10% of the benefits provided by Cardiff urban forest, despite composing 35% of the study area. This could mean residents in the South are less likely to benefit from the ecosystem services provided by trees. This may be particularly significant due to some of the greater concerns from residents in the south over their health.

The PV (present value) of Cardiff's urban trees was calculated at **£44.2 million**. This value represents the discounted value of only the avoided stormwater runoff and air pollution removal services provided by Cardiff's urban forest projected over the next 100 years. It assumes no change in the urban forest. However, recent analyses indicate a decline in canopy cover (NRW, 2016a), suggesting that some loss in the value of the urban forest could occur if this trend continues. The **NPV (Net present value)** of Cardiff's urban trees, was calculated at **£27.8 million**. This value takes into account both the future benefits of the urban forest and its future maintenance costs.

33% of Cardiff's canopy cover is estimated to be owned and managed by City of Cardiff Council. The most commonly found tree species in public ownership were Leyland cypress (17%) and ash (14%). The high proportion of trees in private ownership highlights the role of private tree owners in delivering ecosystem service benefits to the residents of Cardiff. This can represent a risk to the urban forest as there is less control over tree planting and management. However, this can also be an opportunity in educating land and home owners of the benefits of tree planting, species selection and maintenance to better contribute to the sustainability of Cardiff's urban forest and the benefits it provides.

Recommendations

This section provides information on opportunities for Cardiff City Council (CCC) to improve its urban forest for increased benefit provision to those who live and work in Cardiff.

Where to focus tree planting efforts: Undertake GIS based planting assessment, involving Multi Criteria Decision Analysis (MCDA) to identify where there are opportunities to expand the tree and woodland resource in the Cardiff area. This can draw upon the NRW (2016a) assessment of Ward level canopy cover or CCC may seek to undertake an update. The MCDA could involve the incorporation of indicator statistics from the Office for National Statistics (ONS), in-particular the Index of Multiple Deprivation (IMD). Combining IMD with building density and canopy cover, weighted using a relative score within a GIS software program would identify where there is greatest opportunity to improve benefit delivery through increased canopy cover in the areas of greatest need.

What trees to plant and where: Develop a tree planting strategy for Cardiff that will present a tree species selection which will be suited to Cardiff's current and future climate (+3°C 2050 scenario). When commissioning or considering a tree planting scheme as part of any new (or re-)development, a variety of species appropriate to the specific setting should be considered. For trees planted in the harshest of urban settings, having to cope with the most challenging moisture regime, the focus should be on selecting species with higher drought tolerance traits, particularly where provision of adequate soil volume and moisture availability is challenging. For trees having to cope with less challenging settings, for example in parks and greenspaces, species choice will be from a broader palette, as drought tolerance traits will be less critical to tree growth. Caring adequately for newly planted trees, wherever they may be, is critical to survival and independence in the landscape.

Protecting the existing resource: The local authority Tree Preservation Orders can be subjected to regular review with the aim of making sure that all trees worthy of preservation are protected (making new preservation orders where necessary) and that re-planting has been carried out where specified. Creating and updating photographic records of all protected trees is recommended to ensure some measure of tree condition over time can be ascertained. Furthermore, raising public awareness about the value and importance of trees will lead to greater protection through civic engagement.

Master-planning the urban forest's future: CCC could commission a fully costed and multi-faceted urban forest masterplan, with a vision to 2100, that sets targets and priorities to ensure the identified actions are properly implemented and audited. Objectives may include:

- Describe the nature and extent of the urban forest of Cardiff and provide a vision for the future, together with an action plan for delivery and monitoring;

- Set individual canopy cover targets for key land uses and/or geographic areas as Key Performance Indicators, integral to the delivery of the Local Plan;
- Set ambitious targets for cooperative development of the urban forest together with, for example, communities, local business and utility companies;
- Monitor canopy cover as a Key Performance Indicator;
- Identify and prioritise action through planting and management to ensure that tree cover is maintained, sustained and improved;
- Describe the role of trees within the landscape of Cardiff, for example through a Landscape Design Plan;
- Develop a set of principles, standards or policies relating to urban trees that can be used to guide the design, development, and deployment of services delivered by Cardiff's urban trees.

Urban Forest masterplans should cover a variety of disciplines and be incorporated into and referenced by the Neighbourhood or Local Plan, and can contain targets for canopy cover levels for new developments. For example: 'New development will provide a projected 20% canopy cover in 25 years' time'. The species and size combination and layout should be subject to discussion between developers and the local authority.

A previous canopy cover study for Wycombe in Buckinghamshire, showed that densities of 29-34 dwelling/ha could be designed to accommodate projected canopy cover of 26-32%. This projection allowed for the prevailing trend of predominantly low-rise, detached residential development. More attached housing and flatted development, for example, would allow for more communal space with increased canopy cover without sacrificing total dwelling footprint size.

Many factors will combine to influence the delivery of a desired level of future canopy cover in a development; and these include:

- Level of existing canopy cover (i.e. retention of existing trees)
- Guidance and legislation (e.g. BS 5837: 2012 Trees in relation to design, demolition and construction - Recommendations; and the Town and Country Planning Act 1990 (as amended))
- Requirements from new tree planting (i.e. mature tree canopy projection)
- Number, size and crown shape of trees
- Soil requirements (quality and quantity)
- Estimated time to achieve canopy cover target
- Design of layout to accommodate future growth

- Success in establishing trees and achieving longevity in the landscape. As guided, for example, by BS 8545 Trees - From nursery to independence in the landscape.

Incorporating these factors into the urban forest masterplan/strategy would help to engage a variety of stakeholders, including across different departments within the local authority. This is key to incorporating canopy cover targets into the design process of new development.

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References

Adlam, J., 2014. Pest & Disease Management - Giant polypore (9th July, 2014) [WWW Document]. HorticultureWeek. URL https://www.hortweek.com/pest-disease-management-giant-polypore/arboriculture/article/1158279 (accessed 5.18.18).

Alexander, A., Butler, J., & Green, T., 2006. The value of different tree and shrub species to wildlife. British Wildlife, 18(1), 18–28.

CTLA, 1992. Guide for plant appraisal. International Society of Arboriculture, Savoy, Illinois.

ASC, 2016. UK Climate Change Risk Assessment 2017 Evidence Report - Summary for Wales. Adaptation Sub-Committee of the Committee on Climate Change, London.

Baldocchi, D., 1988. A multi-layer model for estimating sulfur dioxide deposition to a deciduous oak forest canopy. Atmospheric Environment, 22, 869-884.

Baldocchi, D.D., Hicks, B.B., Camara, P., 1987. A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. Atmospheric Environment 21, 91-,01.

Baldock, K. C. R., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, L. M., … Memmott, J., 2015. Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. Proceedings of the Royal Society B: Biological Sciences, 282(1803), 20142849.

Bidwell, R.G.S. Fraser, D.E., 1972. Carbon monoxide uptake and metabolism by leaves. Canadian Journal of Botany 50, 1435-1439.

Britt, C., Johnston, M., 2008. Trees in Towns II. London, UK.

BRC, 2018. Database of Insects and their Food Plants. Biological Records Centre. [WWW Document]. URL http://www.brc.ac.uk/dbif/background.aspx (accessed 10.6.18)

BS 5837, 2012. Trees in relation to design, demolition and construction - Recommendations. British Standards Institution, London.

BS 8545, 2014. Trees: from nursery to independence in the landscape - Recommendations. British Standards Institution, London.

Carr, A., Zeale, M. R. K., Weatherall, A., Froidevaux, J. S. P., & Jones, G. (2018). Ground-based and LiDAR-derived measurements reveal scale-dependent selection of roost characteristics by the rare tree-dwelling bat Barbastella barbastellus. *Forest Ecology and Management*, *417*, 237–246.

CCC, 2014. Local Flood Risk Management Strategy. Non Technical Summary. City of Cardiff Council.

CCC, 2015. Cardiff Flood Risk Management Plan. City of Cardiff Council.

CCC, 2017a. Cardiff Liveable City Report. City of Cardiff Council.

CCC, 2017b. Cardiff Green Infrastructure SPG Ecology and Biodiversity. Technical Guidance Note (TGN). City of Cardiff Council.

Cardiff Research Centre, 2012. 2011 Census - Key & Quick Statistics Profile. Cardiff. https://www.cardiff.gov.uk/ENG/Your-Council/Have-your-say/Ask%20Cardiff%20Library/Cyfrifiad%20Cathays%20-%20Cathays%20Census.pdf. Accessed 1.7.18.

CIRIA, 2007. The SuDS manual (C753) [WWW Document]. URL https://www.ciria.org/Resources/Free_publications/SuDS_manual_C753.aspx (accessed 5.18.18).

Connor, E.F., Faeth, S.H., Simberloff, D., Opler, P.A., 1980. Taxonomic isolation and the accumulation of herbivorous insects: a comparison of introduced and native trees. Ecological Entomology 5, 205–211.

Cottrell, J., 2004. Conservation of Black Poplar (*Populus nigra* L.). Forestry Commission Information Note, FCIN57.

Davies, H. J., Doick, K., Handley, P., O'Brien, L., & Wilson, J., 2017. Delivery of ecosystem services by urban forests. Forestry Commission, Research Report, Edinburgh.

DBEIS, 2018. Valuation of energy use and greenhouse gas emissions: Background document. [plus Data tables 1-19: supporting the toolkit and the guidance] [WWW Document]. URL https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal (accessed 4.10.18).

DEFRA, 2010. IGCB Air quality damage costs per tonne, 2010 prices. [WWW Document]. URL http://www.defra.gov.uk/environment/quality/air/air-quality/economic/damage/ (accessed 01.03.2012)

Defra, 2015a. Draft Air Quality Plan for the achievement of EU air quality limit value for nitrogen dioxide (NO2) in Cardiff Urban Area (UK0026). Defra, London.

Defra, 2015b. Air quality: economic analysis. Damage costs by location and source. Defra, London.

Defra, 2016a. Rural Urban Classification. https://www.gov.uk/government/collections/rural-urban-classification.

Defra, 2016b. Modelled background pollution data. Defra. [WWW Document]. URL https://uk-air.defra.gov.uk/data/pcm-data

Department for Transport, 2014. Vehicle Licensing Statistics : 2013. London.

Department for Transport, 2013. National Travel Survey : 2012. London.

Doick, K. J., Peace, A., & Hutchings, T. R., 2014. The role of one large greenspace in mitigating London's nocturnal urban heat island. Science of the Total Environment, 493, 662–671.

Doick, K.J., Davies, H.J., Handley, P., Monteiro, M.V., O'Brien, L., Ashwood, F., 2016a. Introducing England's urban forests. Urban Forestry and Woodlands Advisory Committee, UK.

Doick, K.J., Albertini, A., Handley, P., Lawrence, V., Rogers, K., Rumble, H., 2016b. Valuing the urban trees in Bridgend county borough. Forest Research, Farnham, UK.

Doick, K.J., Albertini, A., Handley, P., Lawrence, V., Rogers, K., Rumble, H., 2016c. Valuing urban trees in the Tawe catchment. Forest Research, Farnham, UK.

Doick, K.J., Handley, P., Ashwood, F., Vaz Monteiro, M., Frediani, K. and Rogers, K. 2017a. Valuing Edinburgh's Urban Trees. An update to the 2011 i-Tree Eco survey – a report of Edinburgh City Council and Forestry Commission Scotland. Forest Research, Farnham. 86pp.

Doick, K.J., Davies, H.J., Moss, J., Coventry, R., Handley, P., Vaz Monteiro, M. Rogers, K., Simpkin, P., 2017b. The Canopy Cover of England's Towns and Cities: baselining and setting targets to improve human health and well-being, in: Conference Proceedings of TPBEIII. Urban Trees Research Conference. 5-6th April. Institute of Chartered Foresters, Edinburgh, UK.

Doick, K.J., Neilan, C., Jones, G., Allison, A., McDermott, I., Tipping, A., Haw, R., 2018. CAVAT (Capital Asset Value for Amenity Trees): valuing amenity trees as public assets. Arboricultural Journal 1–25.

eftec, 2013. Green Infrastructure – Valuation Tools Assessment (NECR126), 1st ed. Natural England, UK.

eftec, 2018. Scoping UK Urban Natural Capital Account - Local Climate Regulation Extension. Defra.

Fini, A., Frangi, P., Amoroso, G., Piatti, R., Faoro, M., Bellasio, C., Ferrini, F., 2011. Effect of controlled inoculation with specific mycorrhizal fungi from the urban environment on growth and physiology of containerized shade tree species growing under different water regimes. Mycorrhiza, 21(8), 703-719

Forestry Commission, 2014. Tree threats – an overview. Edinburgh, UK.

Forestry Commission, 2017. Public Opinion of Forestry 217 - Wales. Statistics. Edinburgh, UK

Forest Enterprise England, 2017. Natural Capital Account 2016-2017. Forestry Commission.

Frediani, K.L., 2015. Tree resource management [WWW Document]. URL http://www.sidmoutharboretum.org.uk/documents/frediani_tree_day_2015.pdf (accessed 18.5.18).

Hall, C., O'Brien, L., Hand, K. & Raum, S., 2018. Evaluation of i-Tree Eco surveys in

Great Britain. Impacts and key lessons: The views of stakeholders. Forest Research, Farnham. 47pp.

Hand, K.L. & Doick, K.J., 2018. i-Tree Eco as a tool to inform urban forestry in GB: a literature review of its current application within urban forestry policy and management context. Forest Research, Farnham.

Hand, K.L., Doick, K.J. and Moss, J.L., 2018a. Modelling the Delivery of Regulatory Ecosystem Services for Large Stature Trees in the Urban Environment with i-Tree Eco. Forestry Commission Research Report (In Press). Forestry Commission, Edinburgh.

Hand, K.L., Doick, K.J. and Moss, J.L., 2018b. Modelling the Delivery of Regulatory Ecosystem Services for Small and Medium Stature Trees in the Urban Environment with i-Tree Eco. Forestry Commission Research Report (In Press). Forestry Commission, Edinburgh.

Hayhow, D.B., Burns, F., Eaton, M.A., Bacon, L., Al-Fulaij, N., Bladwell, S., Brookman, E., Byrne, J., Cheesman, C., Davies, D., De Massimi, S., Elding, C., Hobson, R., Jones, J., Lucas, S.R., Lynch, S., Morgan, L., Rowe, A., Sharp, R., Smith, R.G., Stevenson, K., Stretton, T.A., Taylor, R. & Gregory, R.D., 2016. *State of Nature 2016: Wales*. The State of Nature partnership

Hirabayashi, S., 2013. i-Tree Eco precipitation interception model descriptions. Davey Tree Expert Company, New York, USA.

HM Treasury, 2018. The green book: appraisal and evaluation in central Government. The Stationery Office, London.

Jacob, D.J., Winner, D.A., 2009. Effect of climate change on air quality. Atmospheric Environment 43, 51–63.

Johnston, M., Nail, S., Murray, B., 2011. Natives versus aliens: The relevance of the debate to urban forest management in Britain, in: Trees, People and the Built Environment. pp. 181–191.

Jonsell, M., 2012. Old park trees as habitat for saproxylic beetle species. Biodiversity and Conservation, 21(3), 619-642.

Kendle, A. D., & Rose, J. E. (2000). The aliens have landed! What are the justifications for "native only" policies in landscape plantings? Landscape and Urban Planning, 47(1–2), 19–31.

Kennedy, C.E.J., Southwood, T.R.E., 1984. The number of species of insects associated with british trees: A re-analysis. The Journal of Animal Ecology 53, 455–478.

Key, R.S., 1995. Invertebrate conservation and new woodland in Britain. In: Ferris-Kaan, R. (Ed.), The Ecology of Woodland Creation. Wiley, Chichester, pp. 149–162.

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C., 2018. Urban green space and its impact on human health. International Journal of Environmental Research and Public Health, 15(3).

Lee, J.D., Lewis, A.C., Monks, P.S., Jacob, M., Hamilton, J.F., Hopkins, J.R., Watson, N.M., Saxton, J.E., Ennis, C., Carpenter, L.J., Carslaw, N., Fleming, Z., Bandy, B.J., Oram, D.E., Penkett, S.A., Slemr, J., Norton, E., Rickard, A.R., Whalley, L.K., Heard, D.E., Bloss, W.J., Gravestock, T., Smit, S.C., Stanton, J., Pilling, M.J., Jenkin, M.E., 2006. Ozone photochemistry and elevated isoprene during the UK heatwave of august 2003. Atmospheric Environment 40, 7598–7613.

London Assembly, 2011. Branching Out The future for London's street trees. London.

Lovett, G.M., 1994. Atmospheric deposition of nutrients and pollutants in North America: an ecological perspective. Ecological Applications 4, 629-650.

MacLeod, A., Evans, H.., Baker, R.H.., 2002. An analysis of pest risk from an Asian longhorn beetle (Anoplophora glabripennis) to hardwood trees in the European community. Crop Protection 21, 635–645.

McCauley, D.J., 2006. Selling out on Nature. Nature 443(7): 27-28.

Millennium Ecosystem assessment, 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, DC.

Miller, J.R., 2005. Biodiversity conservation and the extinction of experience. Trends in ecology & evolution, 20(8), 430-434.

Mitchell, C.E., Power, A.G., 2003. Release of invasive plants from fungal and viral pathogens. Nature 421, 625–627.

Morin, R.S., Liebhold, A.M., Luzader, E.R., Lister, A.J., Gottschalk, K.W. and Twardus, D.B., 2005. Mapping host-species abundance of three major exotic forest pests. Res. Pap. NE-726. Newtown Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station. 11 - 726.

Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T.P., Humphrey, K.A., McCarthy, M.P., McDonald, R.E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R.A., 2009. UK Climate Projections Science Report: Climate change projections. Meteorological Office Hadley Centre, Exeter, UK.

NCC, 2014. Towards a Framework for Defining and Measuring Changes in Natural Capital. Natural Capital Committee.

Nielsen, A. B., van den Bosch, M., Maruthaveeran, S., & van den Bosch, C. K. (2014). Species richness in urban parks and its drivers: A review of empirical evidence. *Urban Ecosystems*, *17*(1), 305–327.

Niinements, U. and Valladares, F., 2006. Tolerance to shade, drought, and waterlogging of temperate northern hemisphere trees and shrubs. Ecological Monographs 76, 521-47.

Nowak, D.J., 1995. Trees pollute? A "TREE" explains it all. In: Proceedings of the 7th National Urban Forestry Conference. Washington, DC: American Forests, 28-30.

Nowak, D.J., Civerolo, K.L., Rao, S.T., Sistla, G., Luley, C.J., Crane, D.E., 2000. A modeling study of the impact of urban trees on ozone. Atmospheric Environment 34, 1601–1613.

Nowak, D.J., Crane, D.E., Stevens, J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening 4, 115–123.

Nowak, D.J., Crane, D.E., Stevens, J.C., Hoehn, R.E., Walton, J.T., Bond, J., 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture & Urban Forestry 34, 347–358.

NRW, 2016a. Town Tree Cover in the City and County of Cardiff. Natural Resources Wales, Aberystwyth, Wales.

NRW, 2016b. Tree Cover in Wales' Towns and Cities. Natural Resources Wales, Aberystwyth, Wales.

Ódor, P., Heilmann-Clausen, J., Christensen, M., Aude, E., Van Dort, K.W., Piltaver, A., Siller, I., Veerkamp, M.T., Walleyn, R., Standovár, T. and Van Hees, A.F.M., 2006. Diversity of dead wood inhabiting fungi and bryophytes in semi-natural beech forests in Europe. Biological Conservation, 131(1), 58-71.

ONS, 2012. 2011 Census: Key Statistics for Wales, March 2011. Statistical bulletin. [WWW Document]. URL https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/2011censuskeystatisticsforwales/2012-12-11

ONS, 2017. Principles of Natural Capital Accounting. Methodology. [WWW Document]. URL https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

ONS, 2018a. Environmental accounts. [WWW Document]. URL https://www.ons.gov.uk/economy/environmentalaccounts

ONS, 2018b. UK natural capital: ecosystem accounts for urban areas. Statistical Bulletin. [WWW Document]. URL https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapital/ecosystemaccountsforurbanareas

Palmer, J., Cooper, I., 2011. Great Britain's housing energy fact file. DECC, London, UK.

PHE. 2014. Estimating Local Mortality Burdens associated with Particulate Air Pollution. Public Health England, London.

RHS, 2018a. RHS Plants for Pollinators [WWW Document]. URL https://www.rhs.org.uk/science/conservation-biodiversity/wildlife/plants-for-pollinators (accessed 5.18.18).

RHS, 2018b. Trees for climate change [WWW Document]. URL https://www.rhs.org.uk/advice/profile?PID=712 (accessed 5.18.18).

Richards, N.A., 1983. Diversity and stability in a street tree population. Urban Ecology 7, 159–171.

Rogers, K., Sacre, K., Goodenough, J., Doick, K., 2015. Valuing London's urban forest - Results of the London i-Tree Eco project. Treeconomics, London, UK.

Rumble, H., Rogers, K., Doick, K., Hutchings, T., 2014. Valuing Wrexham's urban forest - assessing the ecosystem services of Wrexham's urban trees: A technical report. Forest Research, Farnham, UK.

Salisbury, A., Armitage, J., Bostock, H., Perry, J., Tatchell, M. and Thompson, K., 2015. Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species? Journal of Applied Ecology, 52, 1156–1164.

Sandifer, P. A., Sutton-Grier, A. E., & Ward, B. P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. *Ecosystem Services*, *12*, 1–15.

Santamour, F.S., 1990. Trees for urban planting: Diversity, uniformity and common sense, in: Proceedings of the Conference Metropolitan Tree Improvement Alliance (METRIA). pp. 57–65.

Schmidt, O., 2006. Wood and Tree Fungi; Biology, Damage, Protection and Use. Springer, Berlin.

Sillman, S., Samson, P.J., 1995. Impact of temperature on oxidant photochemistry in urban, polluted rural and remote environments. Journal of Geophysical Research 100, 11497–11508.

Sjöman, H., Morgenroth, J., Sjöman, J. D., Sæbø, A., & Kowarik, I. (2016). Diversification of the urban forest—Can we afford to exclude exotic tree species? Urban Forestry & Urban Greening 18, 237-241.

Smith, R.M., Gaston, K.J., Warren, P.H. and Thompson, K., 2006. Urban domestic gardens (VIII): environmental correlates of invertebrate abundance. Biodiversity & Conservation, 15(8), .2515-2545.

Southwood, T.R.E., 1961. The number of species of insect associated with various trees. The Journal of Animal Ecology 30, 1–8.

Stewart, H., Owen, S., Donovan, R., R, M., Hewitt, N., Skiba, U., Fowler, D., 2002. Trees and sustainable urban air quality: Using trees to improve air quality in cities. Lancaster University, Lancaster.

Straw, N. A., Williams, D.T., Kulinich, O., Gninenko, Y.I., 2013. Distribution, impact and rate of spread of emerald ash borer Agrilus planipennis (Coleoptera: Buprestidae) in the Moscow region of Russia. Forestry 86, 515–522.

Sunderland, T., Rogers, K., Coish, N., 2012. What proportion of the costs of urban trees can be justified by the carbon sequestration and air-quality benefits they provide? Arboricultural Journal 34, 62–82.

TDAG, 2018. First Steps in Urban Air Quality. Trees & Design Action Group. [WWW Document]. URL http://www.tdag.org.uk/first-steps-in-urban-air-quality.html

Tomlinson, I., & Potter, C., 2010. "Too little, too late"? Science, policy and Dutch Elm Disease in the UK. Journal of Historical Geography, 36(2), 121–131.

Townsend, C.R., Begon, M., Harper, J.L., 2008. Essentials of Ecology. John Wiley and Sons, Chichester.

UK NEA, 2011. The UK National Ecosystem Assessment follow-on: Synthesis of the Key Findings. UNEP-WCMC, LWEC, Cambridge, UK.

Vanhanen, H., Veteli, T.O., Paivinen, S., Kellomaki, S. and Niemela, P., 2007. Climate change and range shifts in two insect defoliators: gypsy moth and nun moth-a model study. *Silva Fennica*, *41*(4), p.621.

Vivid Economics, 2017. Natural Capital Accounts for Public Green Space in London. London.

Webber, J., 2010. Dutch elm disease – Q&A. Forest Research Pathology Advisory Note No. 10. Farnham.

Welsh Government, 2012. State of the Environment. Welsh Government.

Welsh Government, 2017. Household estimates for Wales - households by type by local authority, 1991 to 2016. [WWW Document]. URL https://statswales.gov.wales/Catalogue/Housing/Households/Estimates/households-by-localauthority-yearr (accessed 4.5.18).

Welsh Government, 2018a. Mid-year population estimates (1991 onwards), by Welsh local authorities, English regions and UK countries, for single year of age and gender. [WWW Document]. URL https://statswales.gov.wales/Catalogue/Population-and-Migration/Population/Estimates/Local-Authority/populationestimates-by-localauthority-year (accessed 4.5.18).

Welsh Government, 2018b. National Air Quality Emissions. [WWW Document]. URL https://airquality.gov.wales/maps-data/emissions/national-air-quality (accessed 1.7.18).

Welsh Government, 2018c. Tackling roadside nitrogen dioxide concentrations in Wales. Consultation Document, WG34318. Welsh Government, Cardiff.

Welsh Water, 2017. Summary of household charges 2017-18 [WWW Document]. URL https://www.dwrcymru.com/cy/Business/Our-Charges.aspx (accessed 4.5.18).

Zeale, M.R.K., Davidson-Watts, I., Jones, G., 2012. Home range use and habitat selection by barbastelle bats (*Barabastella barbastellus*): implications for conservation. Journal of Mammology 93(4), 1110-1118.

Zinke, P.J., 1967. Forest interception studies in the United States. In: Sopper, W.E.; Lull, H.W., eds. Forest Hydrology. Oxford, UK. Pergamon Press 137-161.

Appendix I - Detailed Methodology

i-Tree Eco Models and Field Measurements

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 forest structure and its numerous effects (Nowak et al., 2008), including:

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

All field data were collected during the leaf-on season to properly assess tree canopies. Within each plot, data collected included land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, canopy missing and dieback.

Table 18. Land use definitions (adapted from the i-Tree Eco v6 manual)

Land-use	Definition
Residential	Freestanding structures serving one to four families each. (Family/person domestic dwelling. 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	Used predominately for golf as a sport
Agriculture	Cropland, pasture, orchards, vineyards, nurseries, farmsteads and related buildings, feed lots, rangeland, woodland. (Plantations that show evidence of management activity for a specific crop or tree production are included)
Vacant	Derelict, brownfield or current development site. (Includes land with no clear intended use. Abandoned buildings and vacant structures should be classified based on their original intended use)
Institutional	Schools, hospitals/medical complexes, colleges, religious buildings, government buildings,
Utility	Power-generating facilities, sewage treatment facilities, covered and uncovered reservoirs, and empty stormwater runoff retention areas, flood control channels, conduits
Water/wetland	Streams, rivers, lakes, and other water bodies (natural or man-made). Small pools and fountains should be classified based on the adjacent land use.
Transportation	Includes limited access roadways and related greenspaces (such as interstate highways with on and off ramps, sometimes fenced); railroad stations, tracks and yards; shipyards; airports. If plot falls on other type of road, classify according to nearest adjacent land use.
Other	Land uses that do not fall into one of the categories listed above. This designation should be used very sparingly as it provides very little useful information for the model.

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

Calculating the volume of stormwater intercepted by 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.

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 calculations consider both precipitation interception by vegetation and runoff from previous and impervious surfaces. This requires field observation data, collected during the field campaign.

To calculate the volume of precipitation intercepted by vegetation an even distribution of rain is assumed within i-Tree Eco. The calculation 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. This same process is applied to water reaching impervious ground, with saturation of the holding capacity of the ground causing surface runoff. Pervious cover is treated similarly, but with a higher storage capacity over time. The volume of avoided runoff is then summated. Processes such as the effect tree roots have on drainage through soil are not calculated as part of this model. See Hirabayashi (2013) for full methods.

The Standard volumetric rate – Surface water rebated per cubic metre value of £1.3398 set by the Welsh water was used as a representative value of the avoided cost of treating surface water runoff across the whole survey area.

Calculating current carbon storage: biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak, 1995). 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 & Fraser, 1972; Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50% re-suspension rate of particles (Zinke, 1967).

Forest Research are currently developing growth models and leaf-area-index predictive models for urban trees in the UK. This will help improve the estimated value of urban tree stocks in the future.

Replacement costs: are based on valuation procedures of the US CTLA approach (CTLA, 1992), which uses tree species, diameter, condition and location information. In this case values are calculated using standard i-Tree inputs such as per cent canopy missing.

Tree condition: is reported following Nowak et al. (2008) wherein 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.

US Externality and UK Social Damage Costs

The i-Tree Eco model provides figures using US externality and abatement costs. These figures reflect the cost of what it would take a technology (or machine) to carry out the same function that the trees are performing, such as removing air pollution or sequestering carbon.

Official pollution values for the UK are however based on the estimated social cost of the pollutant in terms of impact upon human health, damage to buildings and crops. This approach is termed 'the costs approach'. Values were taken from Defra (2010a) which are based on the 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 2010 prices.

Furthermore, the damage costs presented exclude several key effects, as quantification and valuation is not possible or is highly uncertain. These are listed below (and should be highlighted when presenting valuation results where appropriate).

The key effects that have not been included 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

The CAVAT "quick" method was chosen to assess the trees in this study. To reach a CAVAT valuation the following was obtained:

- the current unit value factor rating
- DBH
- the Community Tree Index rating (CTI), reflecting local population density
- an assessment of accessibility
- an assessment of overall functionality, (that is the health and completeness of the crown of the tree)
- an assessment of safe life expectancy (SLE).

The unit value factor, which was also used in CTLA analysis, is the cost of replacing trees, presented in £/cm^2 of trunk diameter.

The CTI rating was constant across Cardiff at 100%. In actuality therefore, the survey concentrated on accessibility, functionality, appropriateness and SLE.

Accessibility was generally judged to be 100% for trees in parks, street trees and trees in other open areas. It was generally reduced to 80% for trees on institutional land, 40-60% on vacant plots and 40% for trees in residential areas and on agricultural land.

Because CAVAT is a method for trained, professional arboriculturists the functionality aspect was calculated directly from the amount of canopy missing, recorded in the field. For highway trees, local factors and choices could not be taken into account, nor could the particular nature of the local street tree make-up. However, the reality that street trees have to be managed for safety, and are frequently crown lifted and reduced (to a greater or lesser extent) and that they will have lost limbs through wind damage was acknowledged. Thus, as highway trees would not be as healthy as their more open grown counterparts so tend to have a reduced functionality, their functionality factor was reduced to 50%. This is on the conservative side of the likely range.

For trees found in open spaces, trees were divided into those with 100% exposure to light and those that did not. On the basis that trees in open spaces are less intensively managed, an 80% functionality factor was applied to all individual open grown trees. For trees without 100% exposure to light the following factor was applied: 60% to those growing in small groups and 40% to those growing in large groups. This was assumed more realistic, rather than applying a blanket value to all non-highway trees, regardless of their situation to light and/or other trees.

SLE assessment was intended to be as realistic as possible and was based on existing circumstances. For full details of the method refer to www.ltoa.org.uk/resources/cavat.

Appendix II - Species Dominance List

Dominance values for all species encountered during the study (see Section 'Leaf Area' in the Urban Forest Structure sub-chapter).

Rank	Species	Population (%)	Leaf area (%)	Dominance value
1	Common beech	8.20	14.60	22.90
2	Common ash	11.20	11.60	22.80
3	Sycamore	10.40	7.80	18.10
4	English oak	4.60	8.10	12.70
5	European alder	4.90	7.20	12.00
6	Leyland cypress	7.10	3.00	10.10
7	Norway spruce	5.40	4.20	9.60
8	Common Hazel	5.50	3.90	9.40
9	Common holly	4.50	2.40	6.90
10	Common hawthorn	4.60	1.30	5.90
11	Silver birch	3.40	2.50	5.80
12	European larch	2.90	2.90	5.80
13	Small-leaved lime	0.60	3.90	4.60
14	Goat willow	2.20	2.10	4.40
15	Grand fir	1.90	2.00	3.90
16	Western hemlock	1.60	2.00	3.60
17	Norway maple	1.10	1.90	3.00
18	Alder spp.	1.60	0.90	2.50
19	Sweet cherry	0.90	1.30	2.20
20	Hazel alder	1.00	1.00	2.00
21	Japanese larch	0.40	1.70	2.00
22	Western red cedar	0.60	1.30	1.90
23	Apple spp.	0.90	0.60	1.50
24	English elm	1.10	0.30	1.40
25	Aspen	1.00	0.40	1.40
26	Hazelnut spp.	0.90	0.50	1.30
27	Rowan	0.90	0.40	1.30
28	Scots pine	0.20	1.10	1.30
29	Holm oak	0.90	0.30	1.20
30	Raywood ash	0.20	0.90	1.10
31	Silver maple	0.20	0.80	1.10

32	Sweet chestnut	0.60	0.40	1.00
33	Horse chestnut	0.20	0.60	0.90
34	Bay laurel	0.50	0.30	0.80
35	Field maple	0.50	0.30	0.80
36	Wych elm	0.20	0.60	0.80
37	Elder	0.60	0.10	0.70
38	Willow spp.	0.20	0.50	0.70
39	Sessile oak	0.10	0.60	0.70
40	Monterey cypress	0.10	0.60	0.70
41	Hornbeam	0.10	0.60	0.70
42	Strawberry tree	0.50	0.10	0.60
43	Cherry laurel	0.50	0.10	0.60
44	London plane	0.10	0.50	0.60
45	Ash spp.	0.40	0.10	0.50
46	Crack willow	0.20	0.20	0.50
47	Eucalyptus	0.10	0.30	0.50
48	Plum spp.	0.20	0.20	0.40
49	Common fig	0.20	0.10	0.40
50	Hawthorn spp.	0.20	0.00	0.30
51	Monterey pine	0.20	0.00	0.30
52	Copper beech	0.10	0.20	0.30
53	Downy birch	0.10	0.10	0.20
54	Blue spruce	0.10	0.10	0.20
55	Black poplar	0.10	0.10	0.20
56	Cucumber tree	0.10	0.10	0.20
57	Common lime	0.10	0.10	0.20
58	Cheesewood spp.	0.10	0.10	0.20
59	Oak spp.	0.10	0.10	0.20
60	Portugal laurel	0.10	0.00	0.20
61	Maple spp.	0.10	0.00	0.20
62	Elderberry spp.	0.10	0.00	0.20
63	Fullmoon maple	0.10	0.00	0.20
64	Common privet	0.10	0.00	0.10
65	Windmill palm	0.10	0.00	0.10
66	Serviceberry spp.	0.10	0.00	0.10
67	Sycamore spp.	0.10	0.00	0.10
68	Spruce spp.	0.10	0.00	0.10

69	Lawson’s cypress	0.10	0.00	0.10
70	Giant dracaena	0.10	0.00	0.10
71	Golden monterey cypress	0.10	0.00	0.10
72	Yew spp.	0.10	0.00	0.10
73	Lawsonia spp,	0.10	0.00	0.10

Appendix III – 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 condition seems to be most prevalent in the Midlands and the South East of England, although is spreading west. There are now confirmed cases of acute oak decline on the Welsh/English border. Acute Oak Decline poses a threat to 4.7% of Cardiff's urban forest.

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.

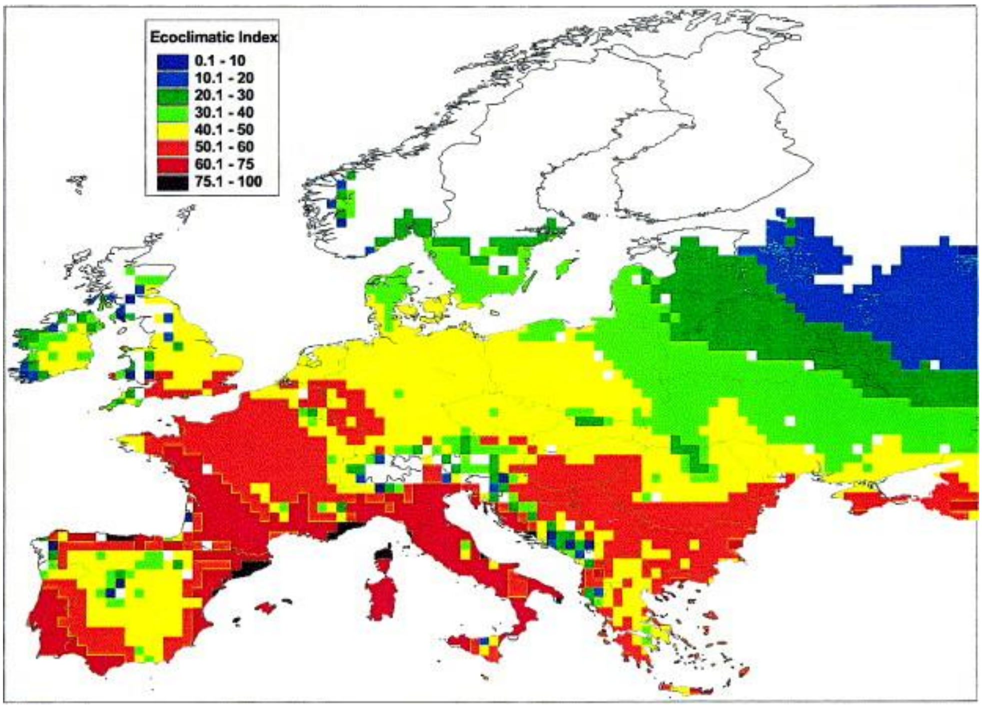


Figure 24. Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB (Ref: MacLeod *et al.,* 2002).

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. 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 24 suggests that Cardiff may be vulnerable to ALB under this model.

If an ALB outbreak did occur in Cardiff it would pose a significant threat to 58.3% 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. (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 *Chalara fraxinea*, targets common and narrow leaved ash. Young trees are particularly susceptible 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. *C. fraxinea* was first recorded in the UK in 2012 in Buckinghamshire and has now been reported across the UK, including in urban areas. There are nine confirmed cases in South Wales since 2013. Ash dieback poses a threat to 11.5% of Cardiff'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 11.5% of Cardiff'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 (Adlam, 2014; Schmidt, 2006). Giant polypore predominantly affects hardwoods such as horse chestnut, beech, cherry, mountain ash and oak. 17% of Cardiff'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 GM in the USA has been slow, invading less than a third of its potential range (Morin et al., 2005). If GM spread to Scotland, it would pose a threat to 19.4% of Cardiff's urban trees.

Oak Processionary Moth

It was first accidentally introduced to Britain in 2005, and it is theoretically possible that if it were to spread it could survive and breed in much of England and Wales. 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 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. The outbreak in London is beyond eradicating, however there are efforts to stop the spread out of London and minimise the impact. There have been no confirmed cases found in Wales to date. OPM poses a threat to 5.8% of Cardiff'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. South Wales has seen numerous cases of *Phytophthora ramorum* in forest stands. South Wales is within the Forestry Commission's Core Disease Zone. *Phytophthora ramorum* poses a threat to 12.7% of Cardiff'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. It was found in five locations in South Wales in 2005 but has since been contained. *Phytophthora kernoviae* is deemed to pose a risk to 18.3% of Cardiff's urban forest and also affects many of the shrub species identified in the survey.

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. However, heavy losses are occurring in some of the large alder populations that occur along western rivers – for example, in the Marches and parts of Wales. *Phytophthora alni* poses a threat to 7.7% of Cardiff's urban forest.

***Dothistroma* needle blight**

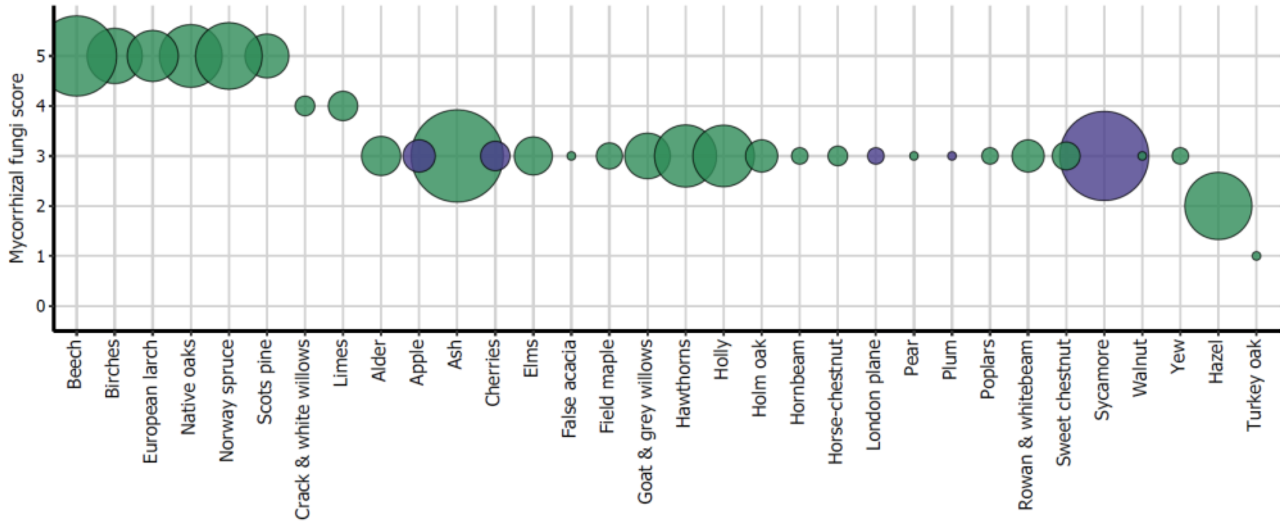
Dothistroma (red band) needle blight is the most significant disease of coniferous trees in the North of the UK. The disease causes premature needle defoliation, resulting in loss of yield and, in severe cases, tree death. It is now found in many forests growing susceptible pine species, with Corsican, lodgepole and, more recently, Scots pine all being affected. It has been found in three of the four Natural Resources Wales' land management areas. While there are no reported cases of red band needle blight on urban trees, 0.25% of Cardiff's urban forest is potentially at threat from it.

Great Spruce Bark Beetle

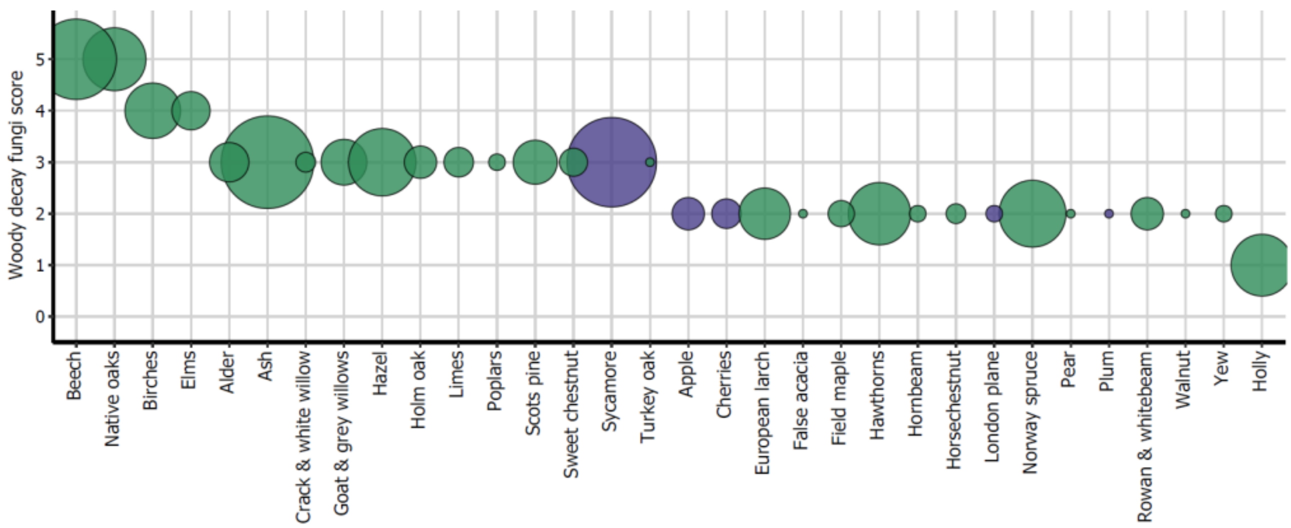
The great spruce bark beetle (*Dendroctonus micans*) damages spruce trees by tunnelling into the bark of the living trees to lay its eggs under the bark, and the developing larvae feed on the inner woody layers. This weakens, and in some cases can kill, the tree. It has become an established pest in Wales but only poses a threat to 5.6% of Cardiff's urban forest.

Appendix IV – Habitat Provision

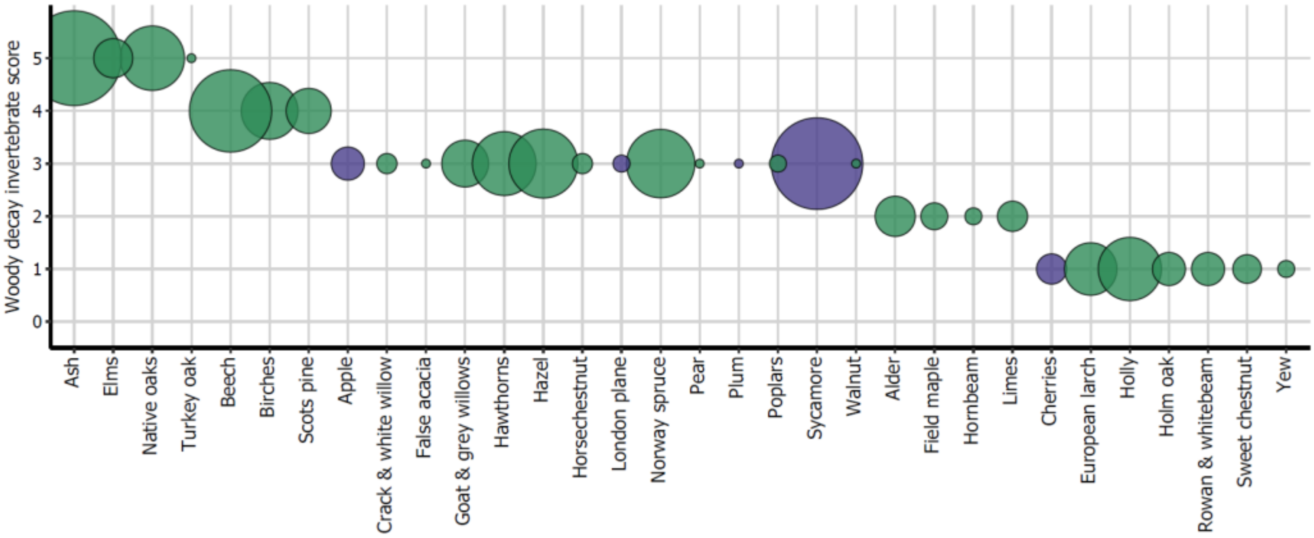
Mycorrhizal fungi value of tree species
Mycorrhiza fungi are essential partners for many plant species and their presence can enhance tree health and growth (Fini et al., 2011). Trees with higher scores provide more species rich and unique associations with mycorrhiza (Alexander et al., 2006).



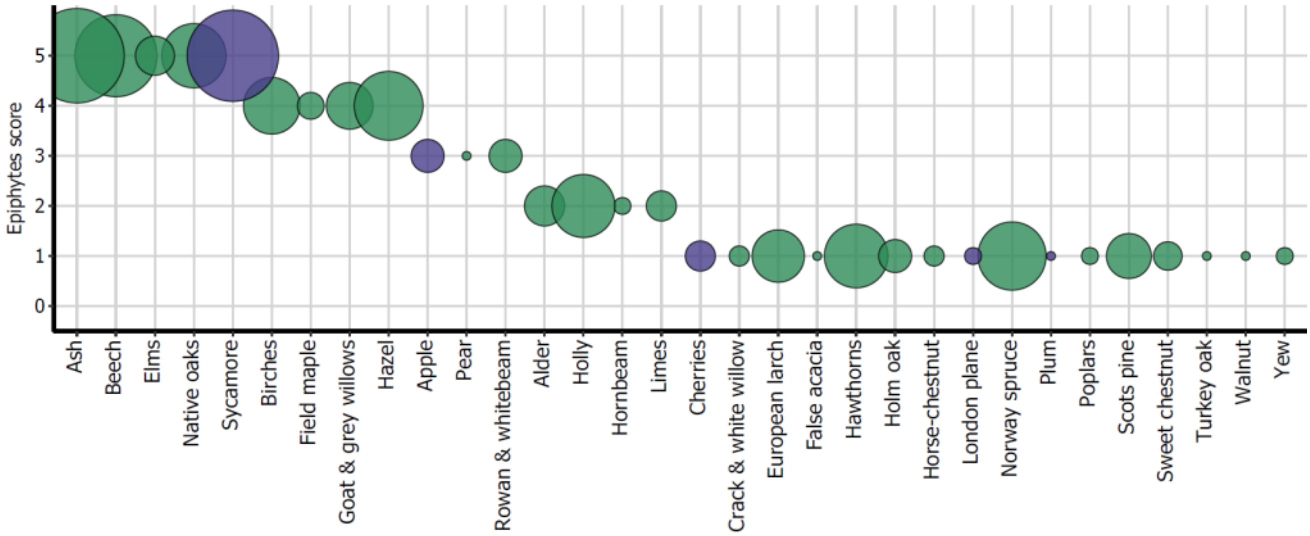
Wood decay fungi value of tree species
Associations between decay fungi and trees is particularly recognised for veteran and ancient trees. Wood decay fungi play an important role in ecosystem functioning. By facilitating wood decay, fungi provide habitats for a range of other organisms (). Older trees are expected to support a greater diversity of wood decay fungi species, but associations can also depend on factors including species, tree size, local climate and conditions (Ódor et al., 2006).



Wood decay (saproxylic) invertebrates value of tree species
Associations between decay invertebrates and trees is particularly recognised for veteran and ancient trees. Many of these invertebrates are thought to at risk due to the loss of old and decaying trees. Old trees can be found in urban areas, usually parks, can host diverse assemblages of saproxylic invertebrates (Jonsell, 2012).

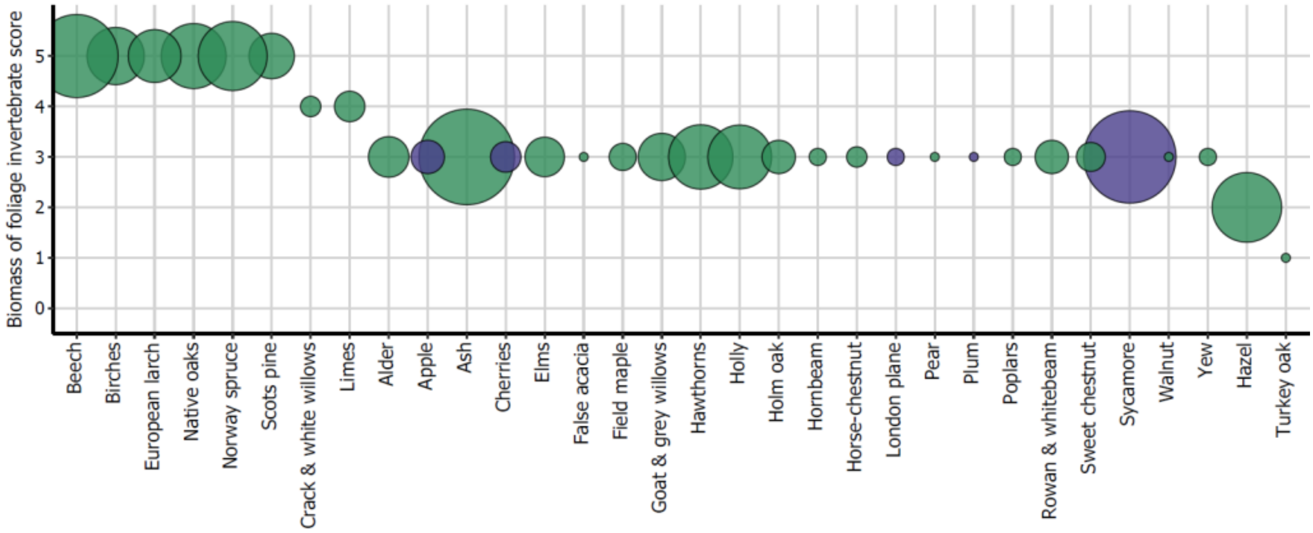


Epiphyte communities value of tree species
Epiphytes, or plants and animals which colonise tree surfaces, usually mosses, lichens etc. Characteristics of tree bark such as texture, acidity and porosity which vary with tree species as well as tree age affect epiphyte assemblages. Conifers tend to perform poorly because their dense foliage blocks light access to trunk and branches. Sycamore performs well for a non-native and supports many rare and threatened species (Alexander et al., 2006).



Biomass of foliage invertebrates value of tree species

Higher biomasses of invertebrates can provide more fruitful foraging environments for birds and bats (Zeale et al., 2012). Some species which provide high species richness also provide high biodiversity value, such as native oaks and birches, while beech and ash support moderate levels of species richness, but comparatively low abundance.



Glossary of Terms

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

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

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

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

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

Council-owned trees – Trees owned and managed by the City of Cardiff Council.

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

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

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

Diameter at Breast Height (DBH) – the outside bark diameter at breast height. Breast height is defined as 4.5 feet (1.37m) above the forest floor on the uphill side of the tree. For the purposes of determining breast height, the forest floor includes the duff layer that may be present, but does not include unincorporated woody debris that may rise above the ground line.

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

Ecosystem services - benefits people obtain from ecosystems.

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

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

Meteorological - phenomena of the atmosphere or weather.

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

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

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

Public trees – Trees found on land-uses which are typically publicly-owned (but not necessarily by the local council) namely parks, cemeteries and transport land-uses.

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.

Volatile organic compounds - one of several organic compounds which are released to the atmosphere by plants or through vaporization of oil products, and which are chemically reactive and are involved in the chemistry of tropospheric ozone production.