Forest Research

Treeconomics

Valuing Edinburgh'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:

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

https://www.forestry/fr/itree

Contents

Key definitions

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

- Rural areas: settlements of less than 3,000
- Urban areas: settlements of 3,000 or more people
- Large urban areas: settlements of 125,000 or more people[1].

Edinburgh: has the second largest population in Scotland and is the capital city. It has a core city area of 11,468 ha and a population of 487,500 (ECC, 2015). Public recreational green space in the city is 33 m^2 per inhabitant (van der Jagt, et. al. 2015).

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

Urban forestry: is defined as 'the management of trees for their present and potential contributions to the physiological, sociological and economic well-being of urban society' (Jorgensen, 1970).

Urban biocultural diversity: a concept emphasizing the links between biological diversity and cultural diversity. Research and policy directed at biocultural diversity can focus on the roles of ethnic or other groups, the role of a cultural practices connected, or not, to certain groups, and to the physical objects or species bearing relationship with specific cultural-historical practices (Maffi and Woodley, 2010).

i-Tree Eco: developed as the urban forest effects (UFORE) model in the 1990's to assess impacts of trees on air quality. It has become the most complete tool available for analysing the urban forest as it includes the most detailed results on the structure and functions of trees. It is 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 Edinburgh's urban landscape.*

A full Glossary is provided on page 86.

1 http://www.gov.scot/Topics/Statistics/About/Methodology/UrbanRuralClassification

Executive Summary

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

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

Valuing the services provided by the urban trees of Edinburgh could allow Edinburgh Council and Forestry Commission Scotland to increase the profile of the urban forest and thereby help to ensure its value is maintained and improved upon.

To gain a better understanding of the urban trees in Edinburgh and to value some of the services they provide, an i-Tree Eco v4 survey was undertaken in 2011 (Hutchings et al, 2012). Since then the i-Tree Eco model evolved and now values a greater range of ecosystem services. This report builds on the 2012 report presenting updated valuations of the ecosystem services already considered in the previous report, plus some additional ones. These valuations have been calculated using the current i-Tree Eco version: v6. This report therefore presents the resulting quantitative assessment revealing some significant benefits. The air pollution removal, carbon sequestration, rainfall interception and public amenity of the urban forest of Edinburgh are summarised.

The data provides detailed information on the forest's structure and its composition. It also demonstrates that residents living in and around Edinburgh benefit significantly from urban trees: In terms of avoided water runoff, carbon sequestration and the removal of two types of air pollutants we estimate that Edinburgh's urban forest **provides citizens ecosystem services worth more than £1.82 million per year**.

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

This study captures a snapshot-in-time. It does not consider how the urban forest has temporally or physically changed over time or the reasons for this change. However, it does start to provide the means to make informed decisions on how the structure and composition of the urban forest of Edinburgh should change in the future and how to ensure that it is resilient to the effects of a changing climate. This study goes a long way to providing the necessary baseline data required to inform decision making for the future. The study was funded by Edinburgh City Council and Forestry Commission Scotland and carried out by Forest Research.

Edinburgh i-Tree Eco Headline Facts and Figures

Total number of trees (estimate)	712,000
Total canopy cover (tree + shrub; %)	17%
Top three most common species	sycamore, holly and silver birch
Proportion of large, medium, small trees (by dbh)	6%, 35%, 59%
Replacement cost (structural value of the trees)	£387 million
Proportion of trees on development land (%)	2%

Values

Pollution removal	195 (per annum)	17 kg per ha[1]
Carbon storage	179,000 (per annum)	16 tonnes per ha[1]
Net C sequestration	4,885 (per annum)	426 kg per ha[1]
Avoided runoff (litres)	183,731,000 (per annum)	16,020 litres per ha[1]
Replacement cost	£3,066 million (CAVAT) £387 million (Structural value)	
Total annual benefit	**£1.82 million** (air pollution removal, carbon storage and avoided runoff)	
Total benefits	**£159 per ha[1]**	

[1] per hectare of study area

Key Results

The urban forest of Edinburgh in 2011:

- had over **712,000 trees**, resulting in an average **urban tree density of 62 trees per hectare**, this is below existing estimates for other areas in the UK
- had a **17% urban tree cover**, equal to an area of 1,950 ha. The trees were primarily found in **residential land, parks** and on **institutional land**
- had a **higher proportion of large trees** than those found in previous i-Tree Eco studies conducted in Scotland and Wales, however this proportion was still below 10%. Edinburgh would therefore benefit from more large sized trees
- had **2%** of trees on vacant land, by definition this canopy is at risk due to development
- included **50 tree and shrub** species, recorded across 8 land use categories
- had **sycamore**, **holly** and **silver birch** as the top three tree species

Edinburgh's trees: (based upon the urban forest structure of 2011)

- intercepted an estimated **183 million litres of water** every year, equivalent to an estimated **£247,375** in sewerage charges avoided
- removed an estimated **195,000 tonnes of airborne pollutants** each year, and the removal of two of those is worth more than **£575,313** in damage costs
- removed an estimated **4,885 tonnes of carbon** from the atmosphere each year, this amount of carbon is estimated to be **worth £1 million**
- stored an estimated **179,237 tonnes of carbon**, this amount of carbon is estimated to be **worth £39.8 million**
- had a **replacement value** of **£387 million**
- had an **asset value** of **£3,066 million**, an evaluation based on public amenity and that is contributing to Edinburgh's status as a leading tourist and enterprise city in Northern Europe

Key Conclusions

- Species mix in the urban forest should be diversified to build resilience to climate change, to the threats posed by emerging pests and diseases and to improve ecosystem service provision by Edinburgh's urban trees.
- The Edinburgh urban forest should be managed to increase the number and diversity of mature large stature trees; these are currently poorly represented yet provide proportionally more ecosystem services than small stature trees.

- The report establishes the potential of urban trees to support and mitigate emerging health priorities associated with lifestyle and urban air pollution. The demonstration of direct benefits from the urban forest needs to be aligned to the strategic planning of the urban forest to maximise these benefits through reviewing the open space strategy, including the findings in the local development plan, and targeting the benefits to achieve priorities of government as part of a joined up approach to health, wellbeing and environmental planning.
- Of the trees recorded, **75% were under private management**. An important resource for the city that is outside of its direct control and that is potentially vulnerable to change not directed by a city tree or urban forest strategy. Increasing awareness of the significance of this resource for everyone who owns and benefits from trees owned by others through an education and engagement programme should encourage proactive management and is considered an important priority goal going forward. By the same notion, a management strategy for Edinburgh's urban forest is required – it should contain a minimum 20-year vision and be reviewed and updated 5-yearly.
- Assessment of the urban forest should be repeated in five years to assess change and monitor progress in line with any future urban forest management strategies. Logically, this assessment should be an i-Tree Eco study to ensure consistency and comparability.

Introduction

When looking to improve the management of a resource and maximise the benefits that it provides to humans it is good practice to undertake a 'baseline' study. An urban forest assessment forms such a 'baseline', a first step in understanding its structure and distribution to then undertake and quantify some of the significant ecosystem services it provides.

The case is well established in support of urban trees through the range of benefits that they provide to humans living in cities, known as "ecosystem services". These benefits would require unprecedented levels of investment in engineered solutions if they were not in place. An advanced analytical model, i-Tree Eco, developed by the US i-Tree Cooperative[2] has been used successfully in over 100 cities globally to evaluate and value such benefits. i-Tree Eco has been tested for its suitability for use in the UK (Rogers et al. 2012) and is rated as fit-for-purpose for valuing UK green infrastructure (Rogers et al. 2012; Natural England 2013).

Report scope and use:

This report provides a baseline for Edinburgh's urban forest – a dynamic resource whose benefits are enjoyed across Edinburgh but are not necessarily optimised in all areas of the city.

Evaluating an assessment such as 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 from development
- identifying areas to enhance through new planting to offset known forecasts of loss
- identifying areas to enhance direct local benefit.

This report can also be used by those writing policy, by those involved in strategic planning to build resilience or planning the sustainable development of the city and region, by those who are interested in local trees for their own and others health wellbeing and enjoyment, and by those interested in the conservation of local nature.

The significance of trees as a major component of the central Scotland's green network has been identified as a significant priority for protection and enhancement in the National Planning Framework (NPF) prepared by the Scottish Government and is incorporated into the Strategic Development Plan (SDP) prepared by the Strategic Planning Development authority at the regional level.

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

In this report, we update the findings of an i-Tree Eco survey undertaken in Edinburgh, Scotland in 2011 to review this significant feature of green infrastructure: namely, the urban forest. 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 the green infrastructure objectives set out in Edinburgh's Local Development Plan and its associated Open Spaces Strategy. These strategic plans, being the principle means for local councils to demonstrate they are complying with central government, set directions at the local level. It also serves to improve the focus of effort to invest in the urban forest through the planned intervention to maximise benefit and avoid costly loss through protection and development, respectively.

Natural Capital and Ecosystem Service Provision

Natural capital refers to the elements of the natural environment, for example the trees and shrubs of an urban forest, that provide valuable goods, benefits and services such as clean air, food and recreation to people. As the benefits provided by natural capital are often not marketable they are generally undervalued and inventories on natural capital are limited. This can lead to wrong decisions being made about the management and maintenance of natural capital.

THE ECOSYSTEM SERVICES PROVIDED TO SOCIETY BY URBAN TREES

- ✓ Urban trees can play an important role in improving the health and comfort of urban residents by filtering and absorbing pollutants and improving local air and water quality (Bolund & Hunhammar 1999), by reducing air temperatures and the so called 'urban heat island' effect (Akbari et al. 2001) and by helping reduce stress levels & improve recovery time from illness (Ulrich 1979).
- ✓ Urban trees also provide economic benefits. They store carbon in their tissues, helping to offset carbon emissions (Nowak et al. 2008). Urban trees help alleviate flash flooding, a problem that can cost cities millions of pounds each year (Bolund & Hunhammar 1999), and commercial and private property value is increased with the addition of trees (Forestry Commission 2010).
- ✓ Trees provide valuable habitat for much of the UK's urban wildlife, including bats (Entwistle et al. 2001) and bees (RHS 2012), and
- ✓ By providing residents with a focal point, urban trees improve social cohesion and aid environmental education (Trees for Cities 2011).

The Millennium Ecosystem Assessment (2005) and the UK National Ecosystem Assessment (2011) provide frameworks to examine the possible goods and services that ecosystems can deliver, according to four categories: provisioning, regulating, supporting and cultural services. The ecosystem services valued by i-Tree Eco plus the other ecosystem services considered within this report are presented in Table 1. Quantifying and assessing the value of the services provided by the natural capital of Edinburgh's urban forest will help raise the profile of the urban trees and can inform decisions that will improve human health and environmental quality.

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

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

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

The Edinburgh i-Tree Eco report can be used to build upon and strengthen use of the findings of the Social Return On Investment (SROI) study of the City of Edinburgh Council's parks. In ascribing a value to the social, environmental and economic change from the perspective of those who experience or contribute to the parks it was possible to provide separate measures and ascribe values of the outcomes achieved as a direct result of the effort put into providing and maintaining the parks. The study looked only at publicly managed spaces under the council's management and therefore provides a narrow window through which to look at the benefits provided by the total green infrastructure of Edinburgh. However, it found that for every £1 spent in the parks a social return of £12 in direct and indirect benefits was perceived by the people surveyed (City of Edinburgh Council, 2014) – see the summary below:

FOR EVERY £1 INVESTED IN THE CITY OF EDINBURGH'S PARKS THERE IS £12 RETURN IN SOCIAL, ENVIRONMENTAL AND ECONOMIC BENEFITS
Other findings include: *Individuals gain health and wellbeing benefits worth around £40.5 million* *Social inclusion and community capacity impact is worth over £6 million* *Local businesses gain additional money from visitors to parks, of around £51 million* *Schools, nurseries and colleges are able to provide outdoor learning experiences valued at just under £1 million* *Visitors gain awareness and understanding of the local environment, and Edinburgh Council's parks make a large contribution to people in Edinburgh feeling healthier, wealthier, smarter, safer and greener* *EDINBURGH COUNCIL (2014)*

For further information on social return on investment visit http://socialvalueuk.org/, and for details on the value of Edinburgh's parks study visit www.edinburgh.gov.uk/info/20064/parks_and_green_spaces/1300/the_value_of_city_of_edinburgh_councils_parks. See also the case study on Edinburgh's urban green infrastructure from the EU Green Surge project at http://greensurge.eu/products/case-studies/Case_Study_Portrait_Edinburgh.pdf.

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 Edinburgh'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 and visitors to Edinburgh. 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, we can assess how the urban forest is changing overtime
- i-Tree Eco requires air pollution data from a single air quality monitoring station and the data used therefore represents a city-wide average, not localised variability

- i-Tree Eco is a useful tool providing essential baseline data required to inform management and policy making in support of the long term health and future of an urban forest, but does not of itself report on these factors
- i-Tree Eco demonstrates which tree species and size class or classes are currently responsible for delivering which ecosystem services. Such information does not necessarily imply that these tree species should be used in the future. **Planting and management must be informed by:**
    - considerations specific to a location, such as soil quality, quantity and available growing space
    - the aims and objectives of the planting or management scheme
    - local, regional or national policy objectives
    - current climate, with due consideration given to future climate projections
    - guidelines on species composition and size class distribution for a healthy resilient urban forest.

Policy context: planning for urban forests in Scotland

An important aspect of the policy context in the UK is the devolution of forestry to the constituent countries with the result that each has its own forest strategy. The Scottish Forestry Strategy identifies the vision, outcomes and objectives that are relevant in urban as well as rural areas (Scottish Government, 2007). The strategy's emphasis which is of relevance to this study comes under Outcome 1 (Improved health and well-being of people and their communities) and Outcome 3 (High quality, robust and adaptable environment).

Regional policy has facilitated a number of urban and peri-urban forestry initiatives, often delivered in partnership - such as those delivering the Woodlands In and Around Towns (WIAT) (Forestry Commission Scotland, 2015). Planning policy is also increasingly promoting urban forestry, albeit usually as part of development, regeneration, urban greening and green infrastructure policy.

Under the 'Planning etc. (Scotland) Act 2006' (*sic*), each local authority has a duty to prepare a Local Development Plan (LDP) that adheres to the National Planning Framework 3 (NPF3) (2014). The NPF3 is the spatial expression of the Government Economic Strategy, setting the context for development planning in Scotland and providing a framework for the spatial development of Scotland as a whole. The development of a green network in the Central Belt region of Scotland is one of the 14 National Developments identified in the NPF. The Central Scotland Green Network Trust (CSGNT), a partnership between governmental agencies, local authorities and Environmental NGOs, is tasked with delivery of the CSGN (Central Scotland Green Network) through strategic funding and lobbying.

The LDP provides guidance on what kind of development should take place within local authority areas and how it might be realised. The LDP also identifies areas for conservation. Each local authority is advised to prepare an Open Spaces Strategy (OSS) under guidance provided in Planning Advice Note 65. A key role of the OSS is to advance the green space planning beyond the traditional approach of quantity indicators to include quality and accessibility indicators. Acknowledging the importance of the human dimension of the enjoyment of urban nature, Edinburgh's OSS includes a quality audit & standards for different types of open space. Neighbourhood Action Plans describe concrete site-specific actions to be taken forward to meet these standards.

The main objective of urban greenspace planning in Edinburgh is to improve the standard of existing green space (i.e. quality & accessibility), minimize the loss of green space to new development and provide adequate open space provision in new development (van der Jagt et al., 2015).

Benefits of tree cover

- Urban tree cover provides economic advantages – a report to the Mersey Forest showed that for every £1 invested in the Forest's programme, £10.20 was generated in increased Gross Value Added (GVA), social cost savings and other benefits
- Trees and urban greenspace improve public health – by improving the environment, urban green infrastructure encourage healthy lifestyles; and, asthma rates among children aged four and five years old are 25% lower for every additional 343 trees per square kilometre.
- Mitigation of the urban heat island effect – trees provide shading and reduce ambient air temperature through evaporative cooling.
- Trees help reduce the risk of flooding – results from Manchester University indicate that tree canopies can reduce surface water runoff by as much as 80% compared to asphalt. The trees also help improve water quality.

Opportunities

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

Social objectives:

- Legal: target effort to deliver urban and regional planning obligations under the Planning (etc.) Scotland Act 2006 (as set out in the LDP & OSS)
- Policy: establish new policy to protect and expand all aspects of Edinburgh's urban forest including under both private and public ownership.
- Evaluation: demonstrate the quality of life benefits being gained through urban greenspace in line with local authority objectives
- Education and advocacy: raise the profile of the urban forest as a key component of green infrastructure that provides many benefits and services to those who live and work in Edinburgh.

Economic objectives:

- Manage Edinburgh's urban forest as an asset, with appreciable return
- 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 to support the environmental, social and economic needs of one of the most popular tourist destinations within NW Europe and retain the status of Scotland's economic centre by industry choice as an attractive place to work and live.

Environmental objectives:

- Resilience:
    - redress imbalance in species mix and age composition profiles; such changes would also help create a forest that is more resilient to the impacts of climate change
    - risk management: identify risks to the tree population such as through even aged populations, pests and diseases, and to plan accordingly
- Recreation:
    - plan for robust green networks to help Edinburgh become a more sustainable urban ecosystem in the future linking together natural, semi-natural and man-made open spaces to create an interconnected network that provides recreational opportunities
    - quality of life: provision of green space to support mental health and wellbeing through near nature experience.

Links

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

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

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

Box 1. What difference can i-Tree Eco make?

i-Tree Eco is still relatively new to the UK - the first study was conducted in Torbay, England in summer 2010. The study revealed that the ecosystem services provided by Torbay's trees were worth £1.4 million per year. This information was crucial in making the case for trees and securing an additional £25,000 to the tree budget in 2011, and again in 2014.

The impact of the London Victoria BiD i-Tree Eco study in 2011 highlighted the dependence of the community on the mature London Plane for delivery of benefits and a tree planting strategy was commissioned to seek to improve the age, size and species structure of the local tree population.

In Wrexham, the local media were so interested in the key findings of their i-Tree Eco study in 2013 that they put the benefit values of the local trees into the limelight before the local authority where able to issue a press release. Such a level of interest by the local press on the positive impacts of trees has not happened before.

Trees in Towns II evidenced that the extent and condition of the UKs urban tree population was declining (Britt & Johnson, 2008). i-Tree is today successfully being used by a wide range of stakeholder s to try and counter this decline. Users include:

- *Local authorities, such as Edinburgh, Glasgow, Swansea, Wrexham, Petersfield*
- *Business Improvements Districts (BIDs), such as Northbank and Victoria BIDs in London*
- *Large land asset-owning agencies, such as Highways England*
- *Community groups, such as the Sidmouth Arboretum and Friends of Lewes*
- *Design teams working on new developments, such as landscape architect JL Gibbons working on Taylor Wimpey's Chobham Manor development in East London.*

Methodology

i-Tree Eco uses a plot based method of sampling, the recorded data is then extrapolated to statistically represent the whole study area. For this study, 200 plots were randomly selected across the City of Edinburgh. The boundaries adopted for the study and the location of the 200 plots are presented in Figure 1.

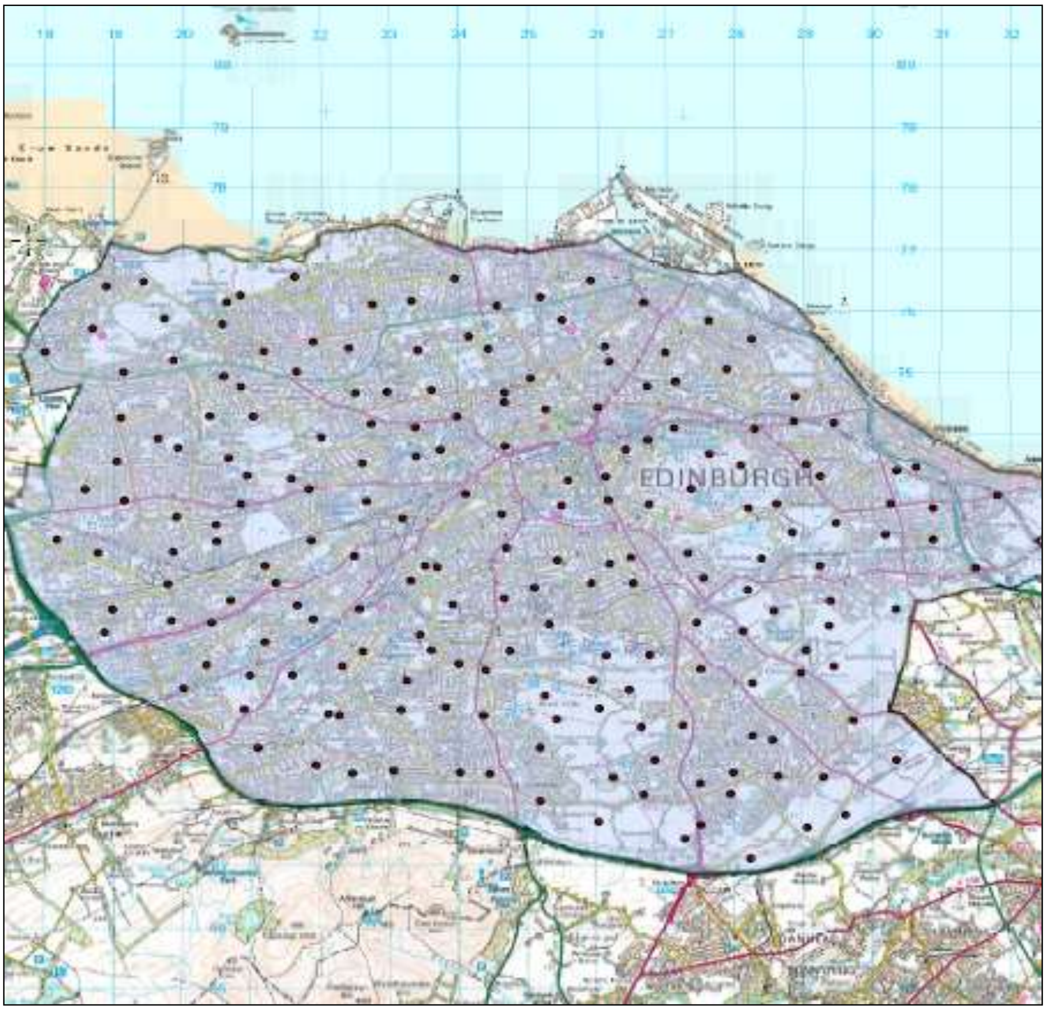


Figure 1. The Edinburgh study area. The sample grid and randomised plots are also shown. (basemap: ©OpenStreetMap contributors).

The total sample area was 11,468 ha, resulting in a sample every 57 ha, a sample density higher than the one used in the Glasgow i-Tree Eco study (every 88 ha). The proportion of plots falling into each of the different land uses is given in Figure 2.

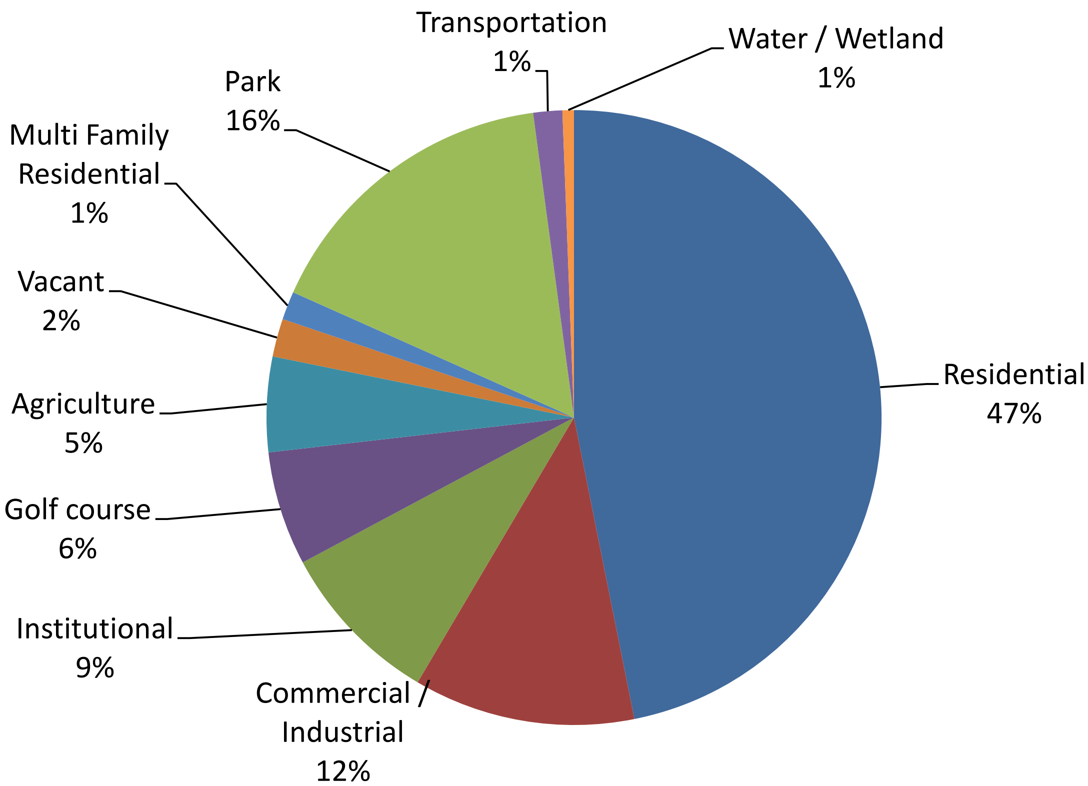


Figure 2. Proportion of plots falling into each of the different land uses (for a definition of land-uses see Appendix 1: Table 14).

i-Tree Eco uses a standardised field collection method outlined in the i-Tree Eco Manual (v6.0 for this study) 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 type of land use, e.g. park, residential
- the percentage distribution of cover present in the plot e.g. grass, tarmac
- the percentage of the plot that could have trees planted in it[3]
- information about trees[4], including the
  - 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
  - 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[5], including the
  - number of shrubs and their species
  - size and dimensions of the shrubs

FIELD SURVEY DATA COLLECTED

Plot information:

- Land use type
- % tree cover
- % shrub cover
- % plantable space
- % ground cover

Tree information:

- Species
- Stem diameter
- Total height
- Height to crown base
- Crown width
- % foliage missing
- % dieback
- Crown light exposure

For the purposes of this study:

[3] plantable space was defined as an area that could be planted with little structural modification (i.e. permeable surfaces such as grass and soil) and that was not in close proximity to trees or buildings such as to hamper their growth.

[4] a tree is defined as a woody plant with a trunk diameter at breast height (DBH; i.e. measured at 1.37 m) that is greater than 7 cm.

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

The field data was collected in 2011 and has been previously reported (Hutchings et al., 2012). This study re-analysed the 2011 dataset to provide a more comprehensive and updated understanding of the ecosystem services provided by Edinburgh's trees. 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, below.

Unlike previous versions of Eco, v6 contains the required climate, weather, phenology and air pollution data and so these were not collated for modelling. Equally, v6 can provide values for ecosystem services based upon UK Social Damage Costs. A summary of calculations is presented below.

Table 2. Outputs calculated based on field collected data.

Urban forest structure and composition	Species diversity, canopy cover, age class, condition, importance and leaf area Urban ground cover types % leaf area by species
Ecosystem services	Air pollution removal by urban trees for CO, NO_2, SO_2, O_3, $PM_{2.5}$ and a value in £ for the removal of NO_2 and SO_2 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	*Pollinating insects* *Insect herbivores (basis for the food chain providing food for birds and mammals such as bats)*
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 (Council of Tree and Landscape Appraisers 1992) valuation method. An amended version of the Capital Asset Value for Amenity Trees (CAVAT) Full Method (Nielan/LTOA 2010) 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. An amended CAVAT full method was chosen to assess the trees in this study, developed in conjunction with Chris Neilan – the primary author of CAVAT. 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 Edinburgh or the wider UK. A risk matrix was devised for determining the potential impact of priority pests and diseases, should they become established in the urban tree population of Edinburgh. The risk matrix was adapted for use where a pest or disease targets a single genus or multiple genera.

Habitat Provision

Trees and shrubs provide valuable habitat and food for many species, from non-vascular plants, such as moss, to insects, birds and mammals. Two examples are included: i) the importance of trees/shrubs for supporting insects generally, and ii) the importance of trees/shrubs for supporting pollinators. Data is not available for all the tree/shrub species encountered in Edinburgh; only species studied in Southwood (1961), Kennedy & Southwood (1984), and RHS (2012) are included.

Summary of Calculations

Variable	**Calculated from**
Number of trees	Total number of estimated trees extrapolated from the sample plots.
Canopy cover	Total tree and shrub cover extrapolated from measurements within plots.
Identification	Most common species found, based on field observations.
Pollution removal value	Based on the US externality cost prices (USEC) or the UK social damage costs (UKSDC) where available: $984 per metric ton CO (carbon monoxide - USEC), $6,930 per metric ton O_3 (ozone - USEC), £14,646 per metric ton

	NO_x (oxides of nitrogen - UKSDC), £1,956 per metric ton SO_2 (sulphur dioxide - UKSDC), and $33,713 per metric ton $PM_{2.5}$ (particulate matter less than 2.5 microns – 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 is Scottish Water's 2013/14 household volumetric waste water rate of £1.3464 per m^3.
Carbon storage & sequestration values	The baseline year of 2013 and the respective 2013 DECC value of £61 per metric ton.
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) method.
Replacement cost (amenity valuation)	Using the Capital Asset Value for Amenity Trees (CAVAT) method.

Comparisons to Other UK i-Tree Eco Studies

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

- Torbay (Rogers et al. 2012)
- Wrexham County Borough (Rumble et al. 2014)
- Glasgow City (Rumble et al. 2015)
- Bridgend County Borough (Doick et al. 2016)
- Tawe Catchment (Doick et al. 2016)

Results and Discussion

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

Sample Area

Based on the sample plots, the tree and shrub **canopy cover of Edinburgh is 17%**, which is higher than the average for Glasgow (15%) and identical to that found in the Wrexham County Borough i-Tree Eco study (17%) (Table 3). While it is higher than the average of English towns: 8% (Britt & Johnston, 2008) a stratified sampling approach was used in their study and therefore a direct comparison cannot be made.

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

	Location					
	Edinburgh	Glasgow	Torbay	Bridgend County Borough	Tawe Catchment	Wrexham County Borough
Study area size (ha)	11,468	17,643	6,375	4,440	6,995	3,833
Sample density (one plot per [...] ha)	57	88	26	22	28	19
Canopy cover (ha)	1,950	2,647	752	533	1,119	652
% Canopy cover	17	15	12	12	16	17
Average number of trees per ha	62	112	105[1]	99	76	95

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

The total size of Edinburgh's urban forest is 1,950 ha. This is approximately 8 times the size of Holyrood Park which covers 260 ha (Figure 3).

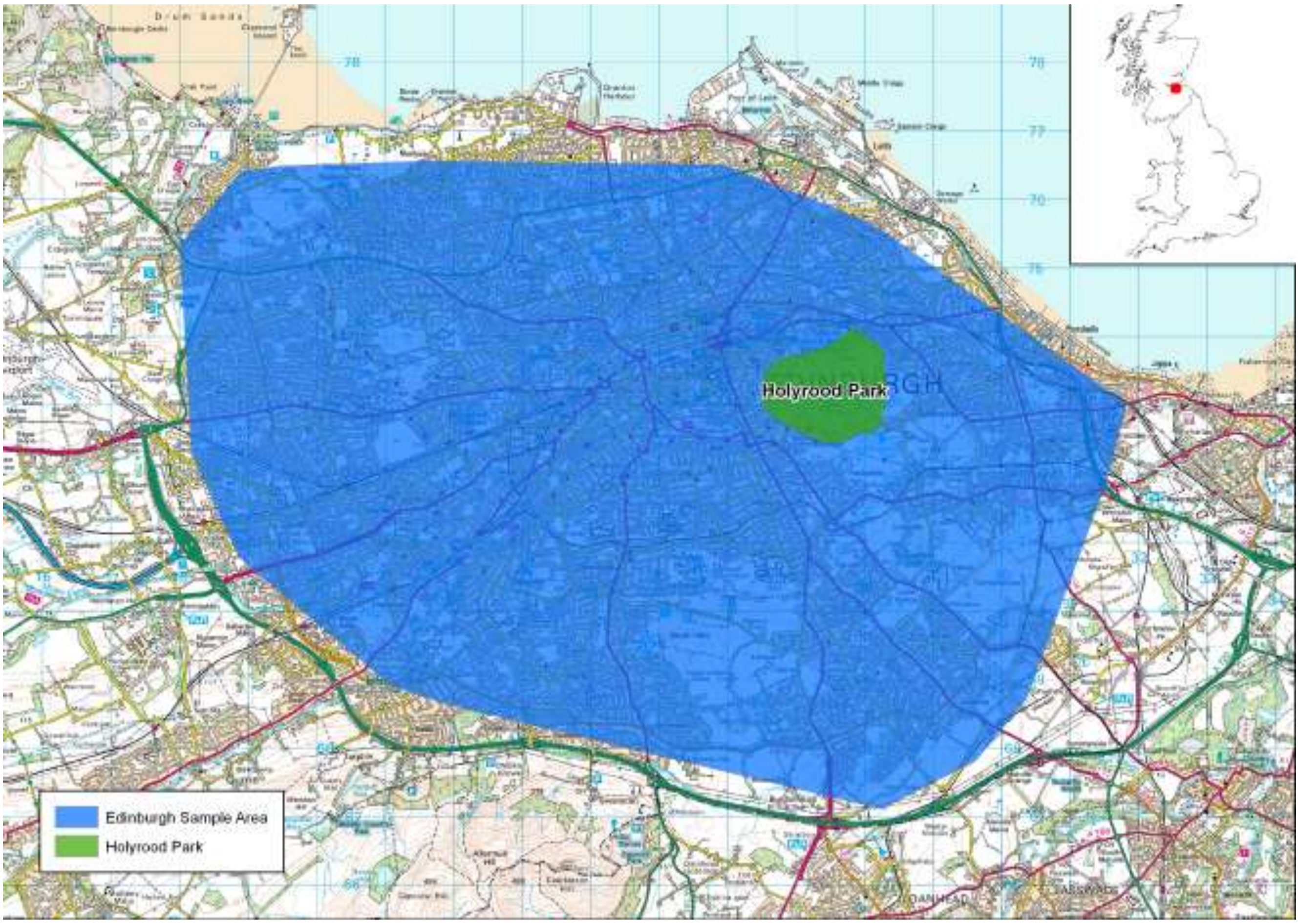
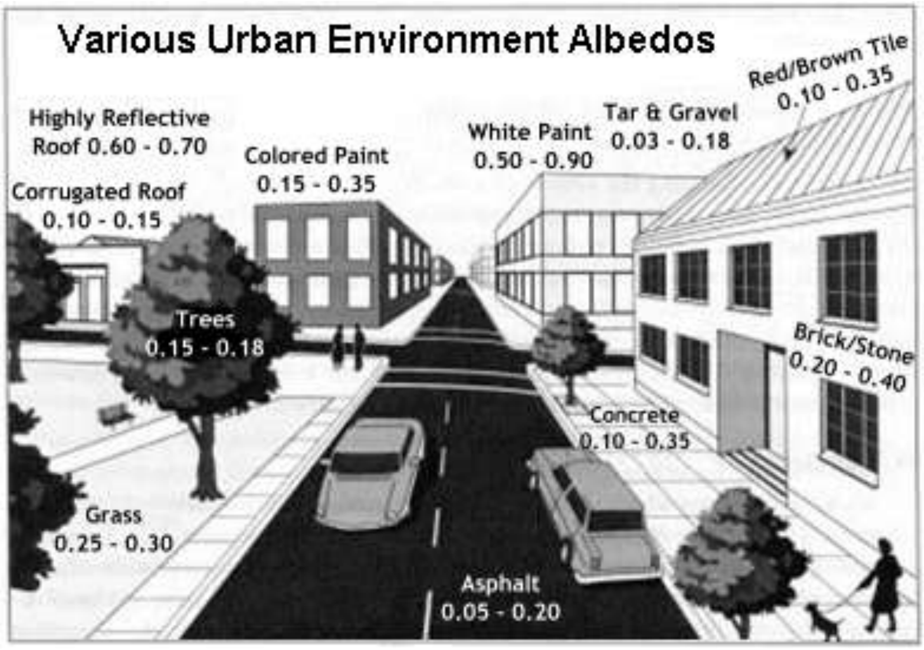


Figure 3. The urban forest of Edinburgh covers a total size of 1,950 ha.

Ground Cover

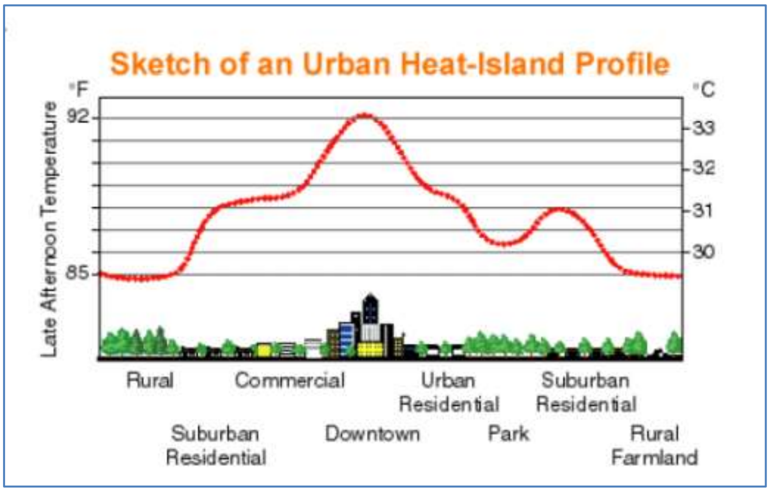
Ground cover in Edinburgh consisted of 55% permeable materials, such as grass and soil; the remainder consisted of non-permeable surfaces such as tar (asphalt), concrete and cement (which contribute to heating of the urban environment - see below). Permeable surfaces can reduce flash flooding and hence the problems associated with flooding, such as travel disruption and damage to infrastructure, and reduce loads on sewer systems. Edinburgh is recognised as an area at risk of flooding (www.edinburgh.gov.uk) - a major flood event in April 2000 left over 750 properties severely damaged, with costs estimated at more than £25 million. At 55%, the percentage of permeable cover in Edinburgh is higher than that reported in the Glasgow city and Wrexham County Borough i-Tree Eco studies (52%) but lower than that in the London i-Tree Eco study (60%).



Source: http://weather.msfc.nasa.gov/urban/urban_heat_island.html

One of the fundamental components that sets a city apart from its rural surroundings is the climate that prevails over urban environments. In urban areas, buildings and paved surfaces have gradually replaced pre-existing natural landscapes. As a result, more solar energy is absorbed, for example into roads and rooftops, causing the summer surface temperature of urban structures to become 10-20°C higher than the ambient air temperatures (Taha, Akbari & Sailor 1992; Taha, 1997). The adjacent image shows albedo values for various urban surfaces, the albedo is a measure of the amount of solar energy reflected by the surface: low albedo implies higher surface temperatures since larger amounts of energy are absorbed. As surfaces throughout the city become hotter, overall ambient air temperature increases. This phenomenon, known as an "urban heat island," 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).

Results from meteorological simulations suggest that cities can help reverse urban heat islands and offset their impacts on energy use simply by increasing the albedo of roofing and paving materials and increasing urban canopy cover. The simulations suggest that reasonable increases in urban albedo can achieve a decrease of 2°C in air temperature and decreases of up to 4°C under some circumstances.



Source: GLA (2006) London's urban heat island: A summary for decision makers

Urban Forest Structure

Species Composition

The urban forest of Edinburgh has an estimated tree population of 711,979. This is a density of 62 trees per hectare, which is lower than in the Glasgow (112 trees per hectare) and Wrexham County Borough (95 trees per hectare) i-Tree Eco studies, but comparable to the English average of 58 trees per hectare (Britt & Johnston 2008). The three most common species are sycamore, common holly and silver birch; and the twelve most common tree species account for 70.8% of the population (Figure 4).

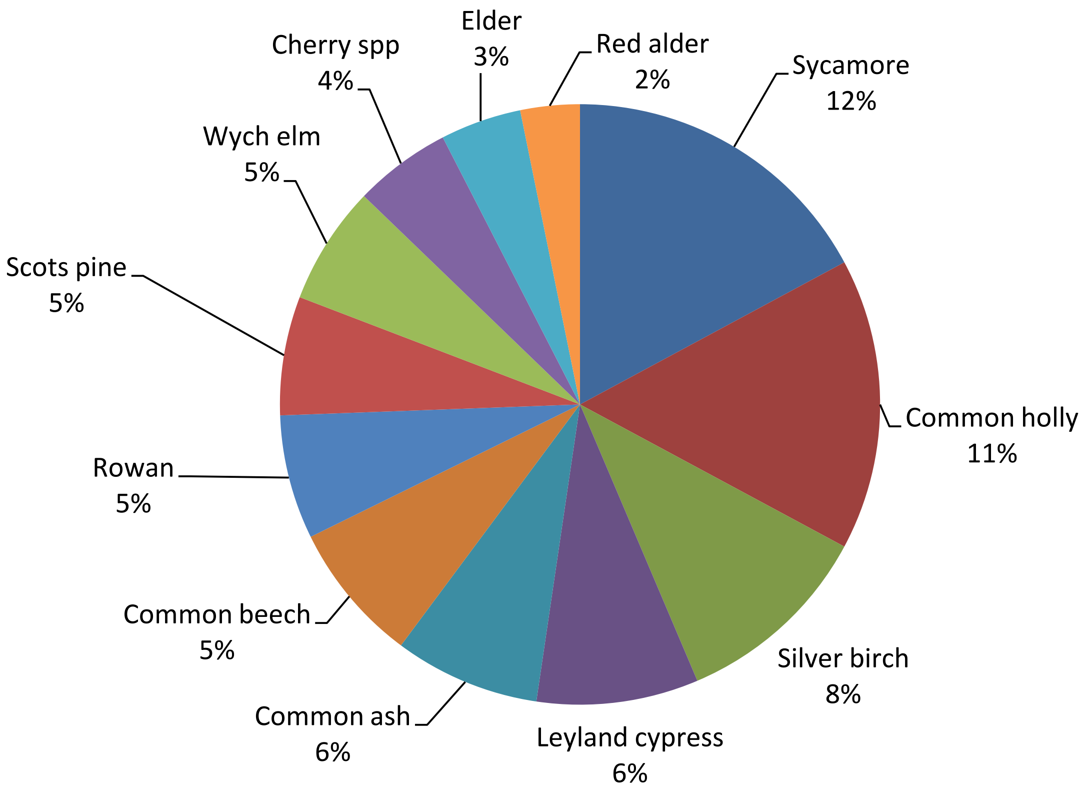


Figure 4. Breakdown of the percentages of the twelve most common tree species in the Edinburgh survey.

Where trees were present, they most commonly occurred on residential land (39%; definitions for each land use type are included in Table 14, Appendix I), park land (23%) and on institutional land (15%; Figure 5). The majority of trees are found in private ownership (75.1%)[6] which has some degree of risk for planning the urban forest due to

[6] 'Private' includes the land-uses: residential, multi-residential, golf-courses, institutional, commercial, agriculture.

its vulnerability unless protected or in long term stewardship (e.g. a woodland grant scheme). Educating on the significance of this shared resource can be a way to mitigate this risk, beyond tree protection. Engagement in stewardship can appeal to those interested in working as a community of good practice, such as observed in Sidmouth and Lewes where urban or civic arboretums have been formed through engaged community and public action (Sidmouth, 2014; Frediani, 2014).

'Public' refers to the land-uses: park, transport, cemetery, vacant

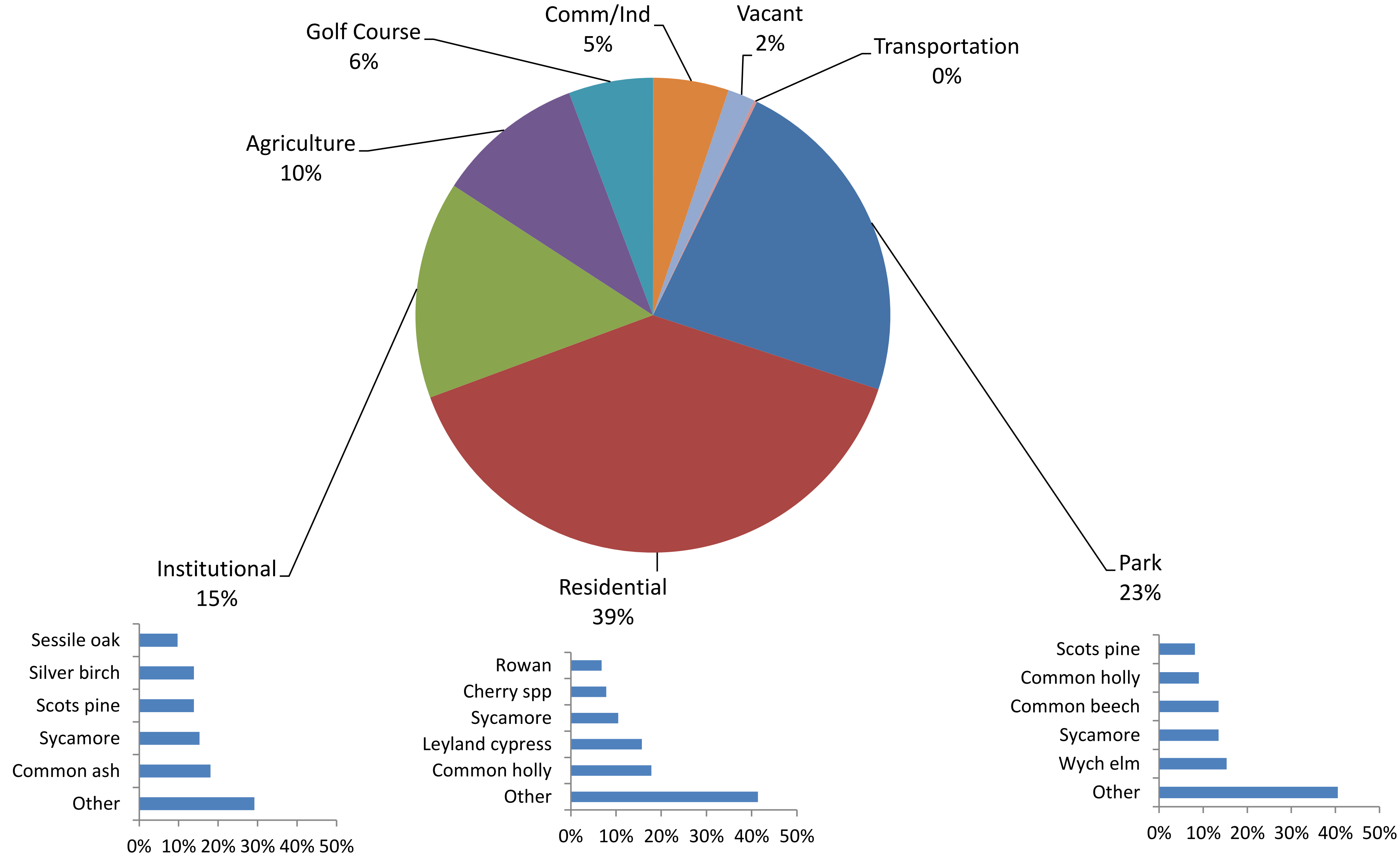


Figure 5. Land use types on which trees were present. Land use types where no trees were found are omitted. Bar charts show the top five tree species in each of the top three land-use types.

Species Composition by Origin

Of those trees identified to species level in the Edinburgh i-Tree Eco study, it is estimated that 53% are native to Scotland (Figure 6). The origin of tree species impacts their ability to 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 (UKCP09 2009). These factors are leading some councils to consider the 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 withstand the effects of climate change better (RHS 2014). However, there is an on-going debate about whether these benefits outweigh the costs of planting exotics (Johnston et al. 2011). 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.

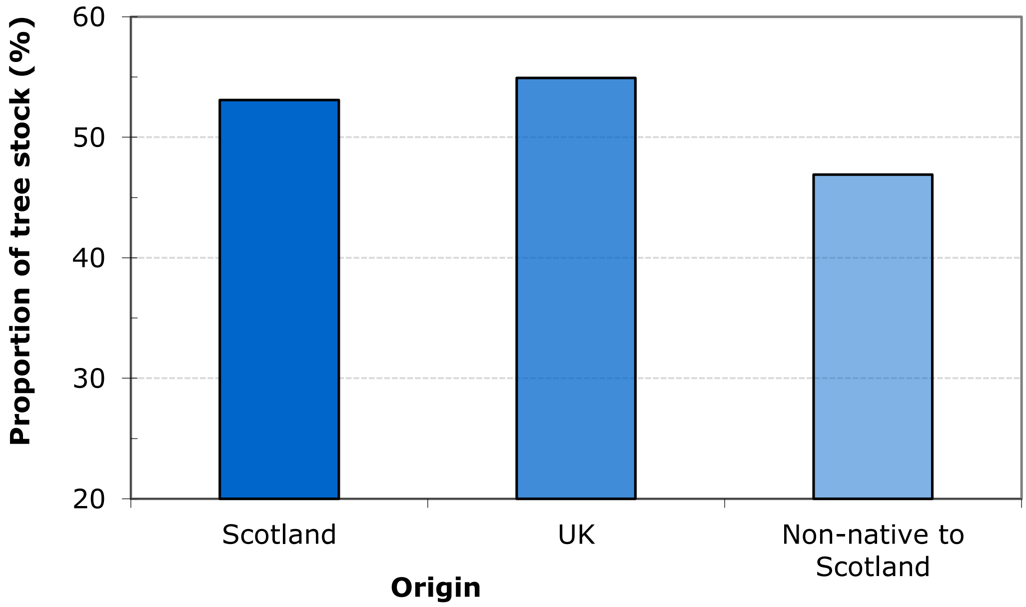


Figure 6. Percentage of tree species native to Scotland and the UK.

Box 2. Targeted management: Tree species diversity

Overall, Edinburgh has lower tree diversity than recorded in i-Tree Eco surveys for other UK cities. Currently there is an over reliance on sycamore (accounting for 12.6%) and its family Sapindaceae (25.2%) to populate the city's urban forest. This leaves it vulnerable to the emerging risks of tree disease, pests and disorders that affect sycamore and its relatives.

Selecting trees to broaden the variety of species and increase the diversity offer of Edinburgh's urban forest will also increase the resilience to the impacts of a changing climate, whilst also increasing the public amenity value (see Box 5) and offering broader support to biodiversity (see Box 8).

The greatest diversity of trees in Edinburgh are growing on residential, park and institutional land.

Influencing residential selection of trees is by definition challenging because it is owned by multiple individuals with different land use objectives. Working to their own interests the tree resource is ultimately decided by what individuals choose to plant. Such tree selection is likely based upon decisions that impact amenity, wildlife value, shade or otherwise shelter and screening provision for the property. Benefits for the wider community are less likely to feature as a priority. Thus, there is a need for regulatory control for important amenity trees, such as through the planning system and, specifically through the use of Tree Preservation Orders for significant trees. However, there is also a need for education and outreach. Edinburgh City Council could pursue such a role alongside initiatives by charities, community groups and other organizations interested in trees and green infrastructure.

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

Species Diversity

A total of 50 tree and shrub species were encountered during the study (for a full list see Appendix II - Species Importance List). This is lower than identified in the Glasgow City (67 species) and Bridgend County Borough (60 species) i-Tree Eco studies, though similar to that identified in the Wrexham County Borough (54 species) 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 (sycamore and common holly). No genus exceeded 20% frequency and no family exceeded 30%. Table 4 outlines the top three species, genus and family frequencies in the Edinburgh survey.

Table 4. Top three frequency tree species, genus and family.

	1st		2nd		3rd	
Species	**Sycamore**	**12.1 %**	**Common holly**	**11.1 %**	Silver birch	7.6 %
Genus	Acer	12.6 %	Ilex	11.1%	Betula	10.1 %
Family	Sapindaceae	25.2 %	Aquifoliaceae	14.4%	Betulaceae	12.2 %

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 Edinburgh's urban forest is 3.2 according to Shannon-Wiener index. This is marginally lower than Bridgend (3.6) but similar to Wrexham (3.1). The highest diversity of trees was found in residential areas (2.8) and parks (2.7) (Figure 7).

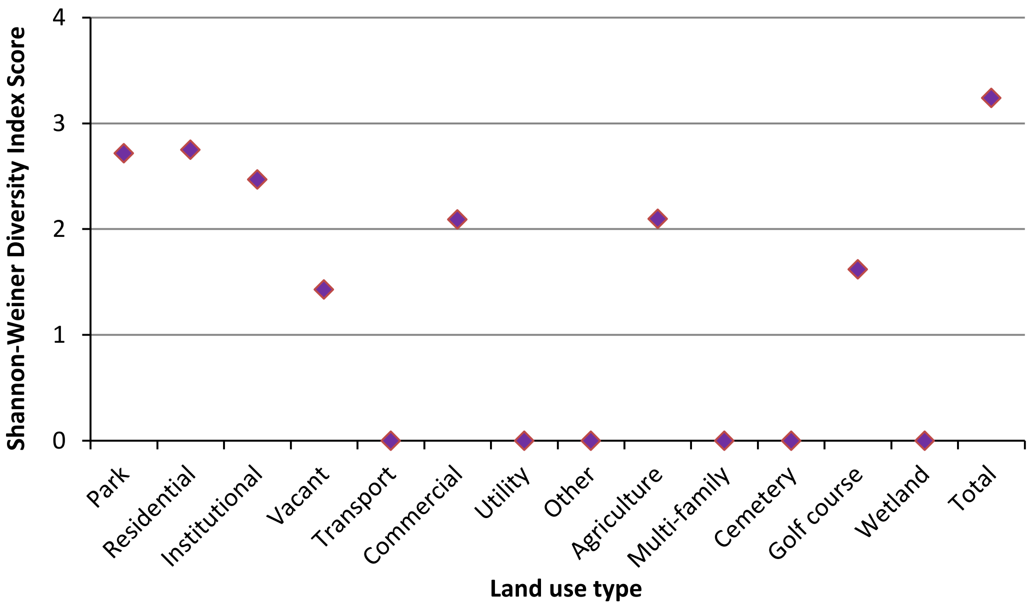


Figure 7. Shannon-wiener diversity index scores for trees on different land use types in Edinburgh.

Size Class Distribution

The size distribution of trees is important for a resilient population. Large, mature trees offer unique ecological roles not offered by small trees (Lindenmayer et al. 2012). To maintain an on-going level of mature trees, young trees are also needed to restock the urban forest and trees need to be planted in a surplus to allow for mortality.

It is estimated that trees with a DBH <20 cm constitute 59.0% of the total tree population in Edinburgh (Figure 9a). The number of trees in each DBH class then declines successively, where trees with a DBH >60 cm make up 6.2% of the tree population.

Analysis of only large stature trees[7] shows that 60 cm+ diameter trees account for 8.1% of the tree population (Figure 9b), which is lower than the 10% value suggested by Richards (1983) as necessary to ensure a healthy stock of street tree. The proportion of trees with diameters between 40 and 60 cm is also low; suggesting that the population of large stature trees is comprised of a very high proportion of young immature trees and that there is a shortage of trees that will mature into large diameter trees in the future.

Analysis of only the small stature trees[8] is shown in Figure 9c. These trees will not typically attain large stature and therefore there are high numbers of these trees in the lowest DBH class. However, approximately one quarter is in the 20-40 cm DBH class, suggesting a good population of mature small stature trees in Edinburgh.

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

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

There is evidence to suggest that large trees provide more ecosystem services than small stature ones and provide more benefits compared to their costs (USDA 2003; Sunderland et al. 2012). Little work has been conducted to investigate ecosystem service provision of mature small stature trees growing, such as produced by goat willow, so a comparison is difficult. However, it is recommended that small stature trees are supplemented with young, large stature trees to ensure a large tree component of the urban forest in the future, while retaining the potential benefits that small stature thickets may provide.

Box 3. Diversity in tree size

Across the UK i-Tree Eco surveys are finding that our urban landscape shares a high proportion of trees with similar size classes. For the most part, the Edinburgh survey confirmed such findings – it is estimated that trees with a DBH <20 cm constitute some 60% of the total tree population, while trees with a DBH >40 cm only constitute 16%

In Edinburgh, as observed in Glasgow, large trees were less aggregated by land use type than in Torbay and Wrexham – they were found across a number of land use types. However they were surprisingly absent from cemetery and multi-residential land. Larger trees tend to occur where land use is unlikely to have changed in recent history, where a lack of disturbance can play an important role in these trees being able to grow to maturity – land uses such as cemeteries and parks. The relatively low abundance of large trees on vacant land, cemeteries and - indeed - commercial land and their high abundance in park and on institutional and agricultural land point to opportunities for education and long-term planning.

The generally low frequency of 40-60 cm DBH trees over all land uses results in a missing age class of trees coming through to replace the mature trees.

The land use with the largest proportion of 20-40 cm DBH trees is currently 'transport'. Given that highway maintenance practices are often high intervention and are cyclical in nature they tend to limit the maturing of large stature trees along carriageways. The i-Tree Eco results herein reflect this short cycle of planting and removal, when compared to other areas, with almost all trees failing to get beyond 20 cm girth.

Urban planners in Edinburgh have an opportunity to explore these anomalies while seeking to continue to conserve and expand the breadth 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 we found.

Fortunately, there is a high proportion of small trees (7-20 cm DBH), providing a reservoir that can be fostered through careful management to maturation. This will help to address the generally low levels of medium and large stature trees and improve size diversity across the urban forest. A programme of planting would also ensure an on-going presence of small trees.

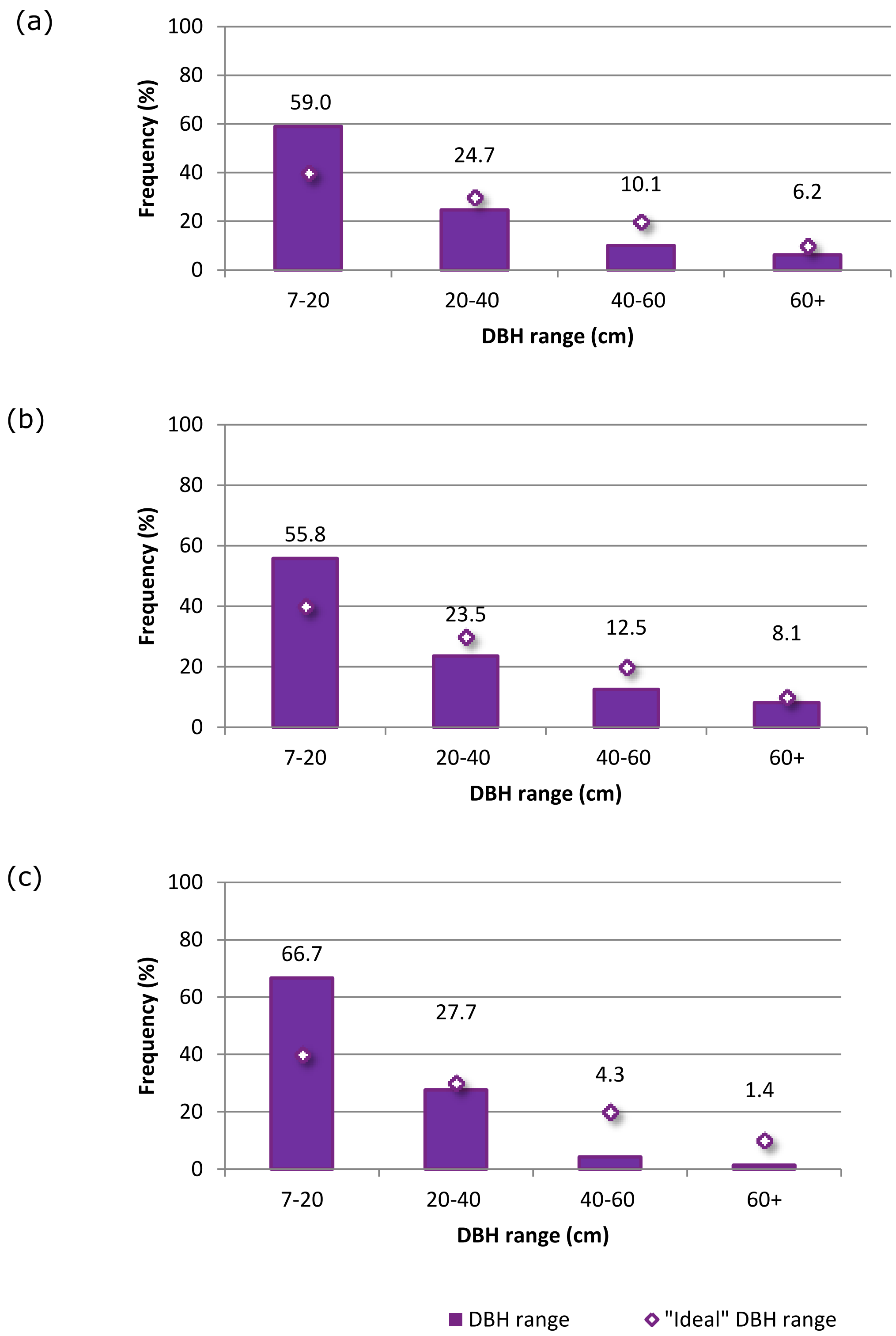


Figure 9. DBH ranges of trees (a) encountered in the Edinburgh survey , (b) encountered, with small stature trees removed from the analysis and (c) encountered in the Edinburgh survey, with large stature trees removed from the analysis (with data values shown for clarity). Diamonds represent recommended frequencies for that DBH class as outlined by Richards (1983) i.e. 40, 30, 20, 10%.

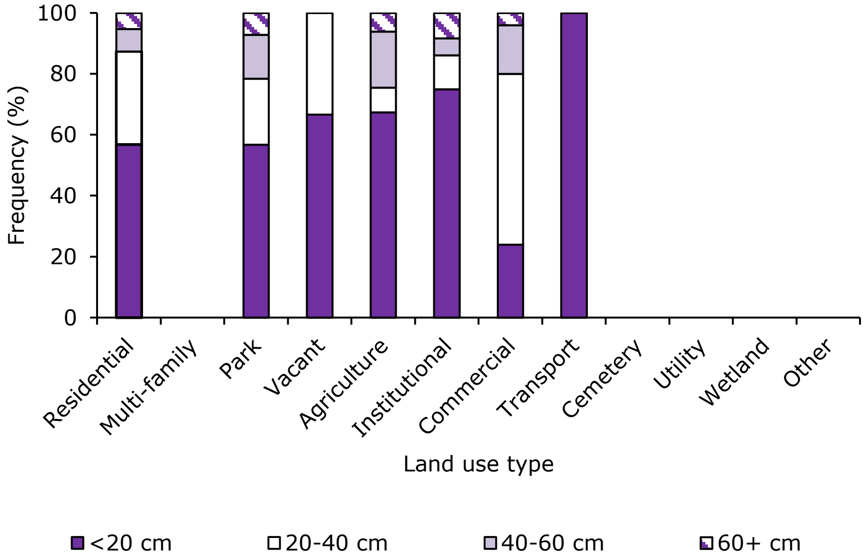


Figure 10. Proportion of diameter size classes per land use type. A missing value denotes land use types where no trees were found.

Small trees (<20 cm DBH) were highest in proportion on transportation, institutional and agricultural land (Figure 10). Large trees (>60 cm DBH) were highest in proportion on institutional land and parks (Figure 10).

Tree Condition

The condition of Edinburgh's trees was extremely good, with 71% of trees in excellent condition, 16% in good and 7% of trees in fair condition[9] (

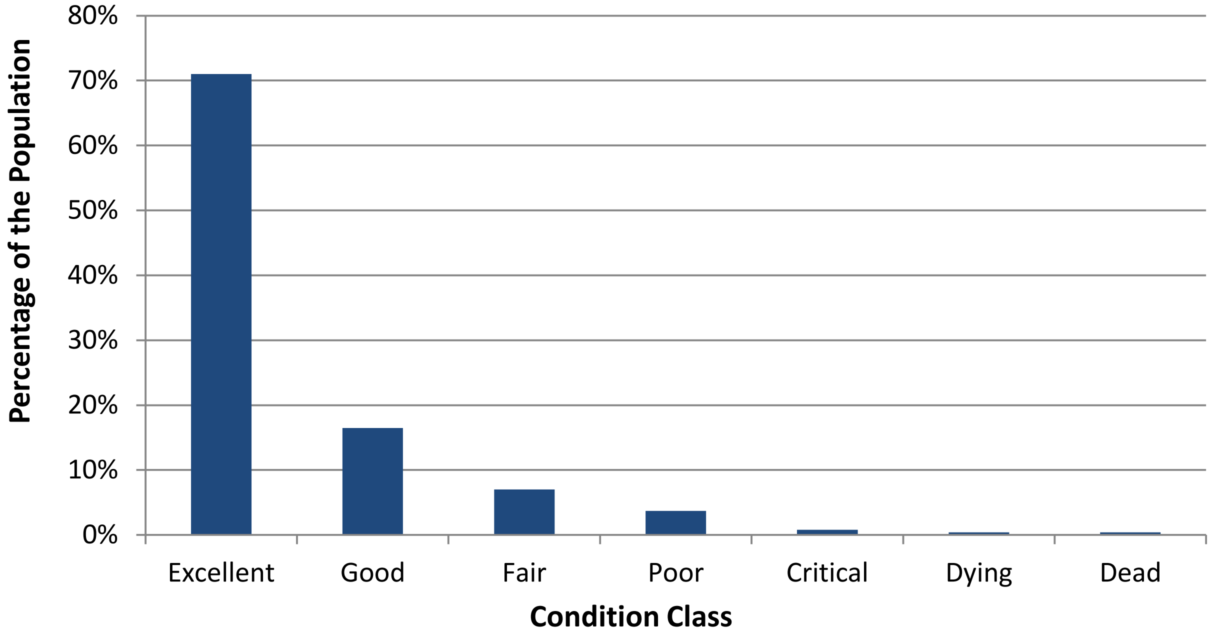


Figure 11). A total of 5% of Edinburgh's trees are estimated as being in 'poor', 'critical', 'dying' or 'dead' condition. A proportion of dead trees is important because of their contribution to biodiversity.

Tree condition across Edinburgh was worse than reported for Glasgow's trees: 90% in excellent condition. However, it was more comparable to that reported in the Bridgend County Borough i-Tree Eco study (87% of trees in excellent condition and 6% in the poor to dead ratings) and much better than across Wrexham County Borough (58% excellent, 13% in the poor to dead condition categories).

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

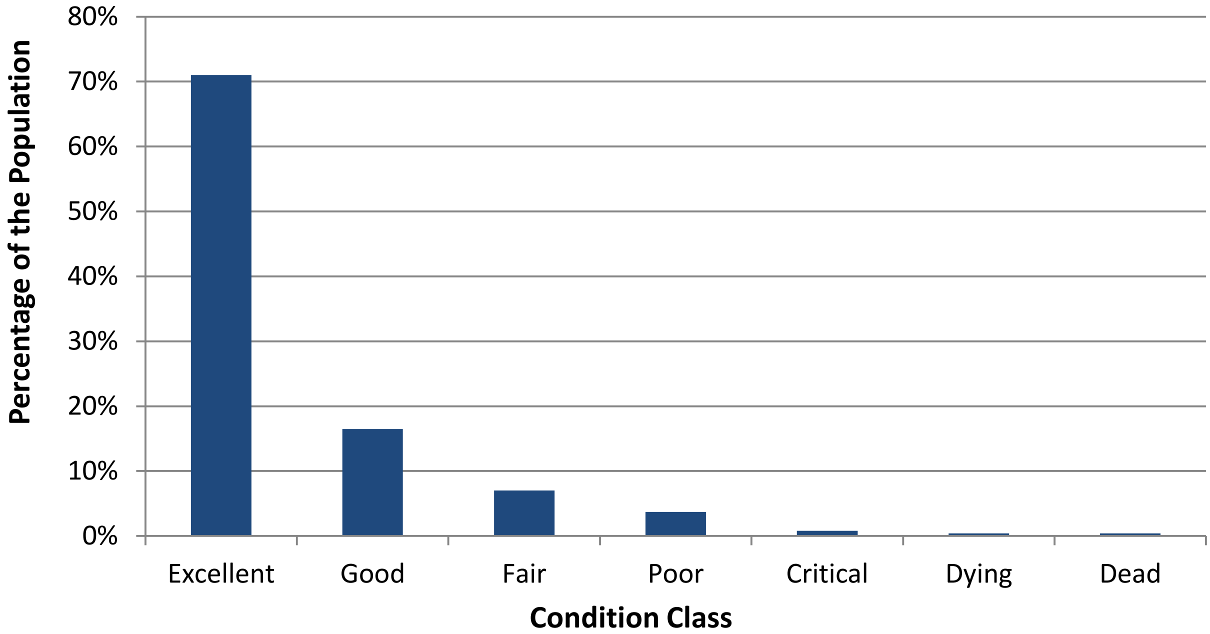


Figure 11. Condition of trees encountered in Edinburgh.

Condition is a useful measure of the potential prevalence of pests or diseases and the need for further enquiry, for example follow up surveys may be targeted at specific species where a trend is observed. Figure 12 shows the condition of the top ten most commonly encountered trees across Edinburgh and reveals that elder and red alder had the lowest proportion of trees in 'excellent' condition; on the other hand common holly and Leyland cypress had a high proportion of their total population in the 'excellent' category.

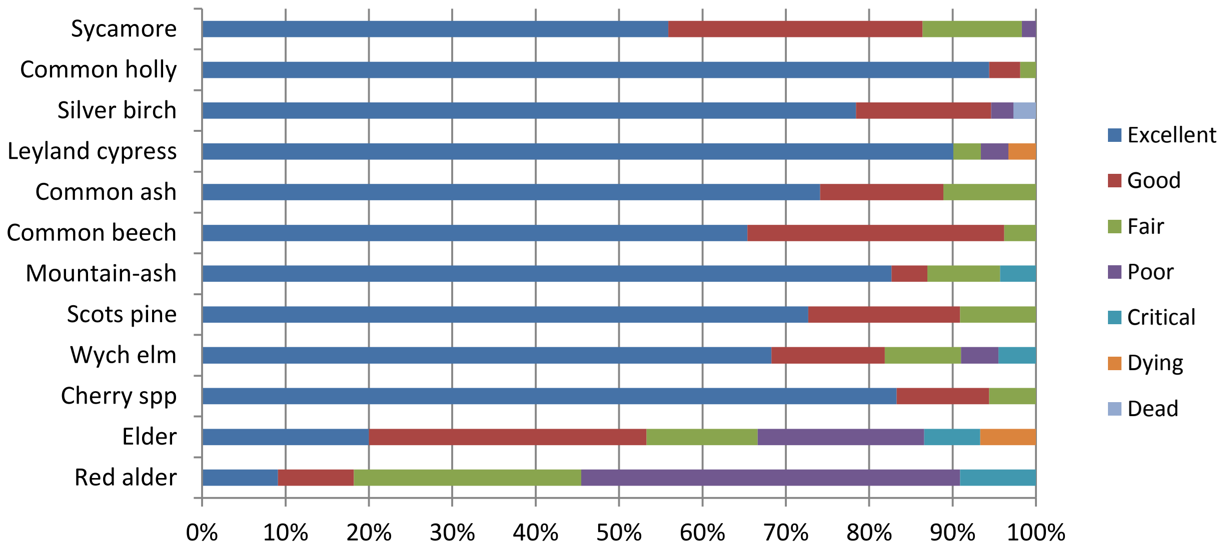


Figure 12. Condition of the top ten most commonly encountered trees across Edinburgh.

Leaf Area and 'Importance 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 Edinburgh's trees is 73.9 km^2; this is approximately twice the size of Aberdeen's urban area of 41.2 km^2; based on the Ordnance Survey's 1:625,000 scale GB BaseData map). Sycamore, Prunus spp., and common beech provide the most leaf surface area (25%, 12% and 7%, respectively) (Figure 13).

TREE SPECIES THAT CONTRIBUTE THE MOST LEAF SURFACE AREA:

Sycamore

Prunus spp

Common beech

Importance value is calculated in i-Tree Eco as the sum of leaf-area and population size as an indication of which tree species within an urban 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 Edinburgh study, by importance value, were those which appeared in greater numbers such as birch and holly, and those with large leaves, such as sycamore and ash. A list of the importance values for all 50 species encountered during the study is presented in Appendix II - Species Importance List.

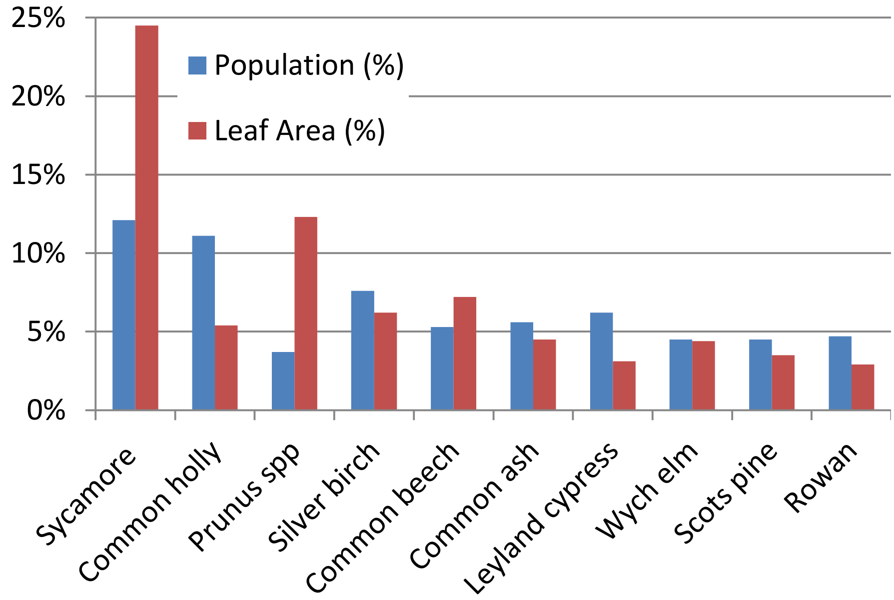


Figure 13. Percentage population and leaf area of the ten most important tree species in Edinburgh.

THE TOP TEN MOST IMPORTANT TREES IN EDINBURGH:

Species	I.V.
Sycamore	36.6
Holly	16.5
Prunus spp	16.0
Silver birch	13.8
Common beech	12.6
Common ash	10.1
Leyland cypress	9.3
Wych elm	8.9
Scots pine	8.0
Mountain ash	7.7

Box 4.Tree 'Importance Value'

The scientific models that underpin i-Tree Eco reveal a direct relationship between leaf area and the provision of ecosystem services. Thus, tree Importance Value is calculated in i-Tree Eco as the sum of leaf area and population size and it is the most common trees which also have larger leaves or large tree canopies that tend to rank higher in importance.

Sycamore, holly and cherry are the three most important trees with this regards in Edinburgh's urban forest; a consequence of their relative contributions to the total tree population and size. This is unusual when comparing the Edinburgh tree inventory with other UK i-Tree Eco studies as large stature and high leaf area trees such as oak tend to complement sycamore having the highest importance value. Holly and cherry are neither large stature nor large leafed.

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

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

Birch, beech and ash are the species with the fourth, fifth and sixth highest importance value in this study. Care of these, together with supplementary planting of more limes and evergreens such as Scots pine (also in the top ten in this study) would be an effective means to increase ecosystem service delivery across Edinburgh's urban forest. The potential to explore suitable species in conjunctions with the Princess park, Edinburgh Botanic Garden and Zoological gardens should also be explored.

Replacement Cost and Amenity Value

CTLA valuation

The urban forest of Edinburgh has an estimated **replacement value of £387 million** according to the CTLA (Council of Tree and Landscaper Appraisers) valuation method. This is the cost of replacing the urban forest of Edinburgh should it be lost; this valuation method does not take into account the health or amenity value of trees.

CAVAT valuation

The urban forest of Edinburgh has an estimated **public amenity asset value of £3,066 million** according to CAVAT valuation, taking into account the health of trees and their public amenity value. The sycamore trees in Edinburgh had the highest overall value (Figure 14, Table 5), representing 30% of the total public amenity value of all of trees in Edinburgh's urban forest. The single most valuable tree encountered in the study was an English oak, estimated to have an asset value of £63,512.

CAVAT – Capital Asset Value of Amenity Trees

Trees and woodlands have a structural value that is based on the replacement cost of the actual tree.

Large, healthy long lived trees provide the greatest structural and functional value, which translates in to the greatest CAVAT [amenity] values.

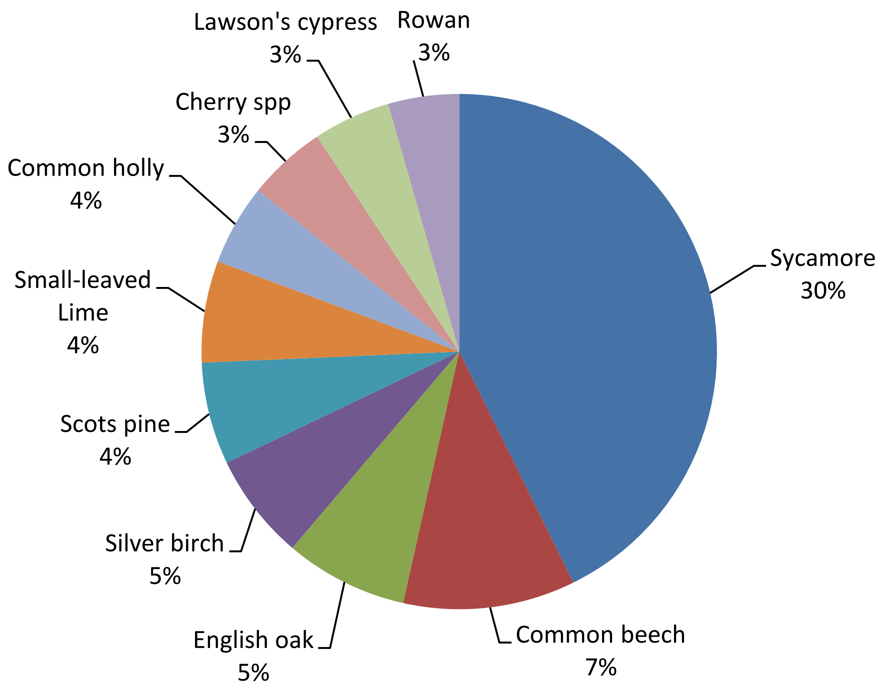


Figure 14. Ranking of the top-twelve tree species according to their CAVAT valuation.

Table 5. CAVAT values for the top twelve trees by genus.

Genus	Number of species	Value of measured trees	Total value across Edinburgh (in millions)
Acer	2	£665,726	£954.3
Tilia	4	£193,970	£278.0
Quercus	5	£183,680	£263.3
Fagus	1	£160,278	£229.8
Betula	3	£113,414	£162.6
Ulmus	2	£105,547	£151.3
Pinus	1	£95,215	£136.5
Prunus	4	£92,929	£133.2
Ilex	1	£75,262	£107.8
Fraxinus	2	£74,367	£106.6
Cypressus	1	£71,803	£102.9
Sorbus	2	£68,746	£98.5
Total	**28**	**£1,900,937**	**£2,724.8**

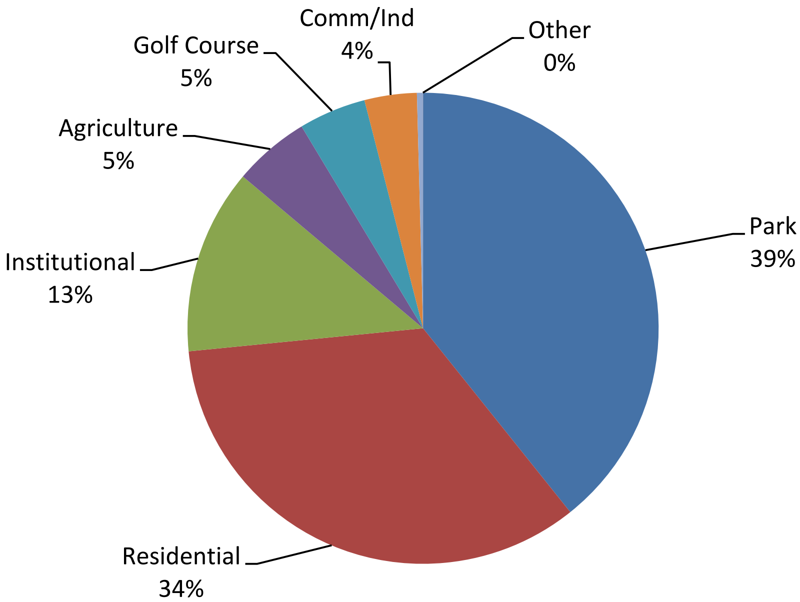


Figure 15. Percentage public amenity value held by trees in Edinburgh according to land use type.

The land use type containing the highest CAVAT value of trees is 'park', with over a third of the total value of the trees and estimated value of approximately £839,608. This equates to greater than £1,203 million when extrapolated for the whole of Edinburgh. Vacant land and transportation land, collectively, contained the lowest percentage of public amenity value trees in this study, <1% of the total value (identified as 'other' in Figure 15). 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. Given the excellent condition of trees observed across Edinburgh (see Tree condition for further details), this result would seem to be a consequence of the small percentage contribution of these land-uses to the tree population and the study overall.

Box 5. 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. There are two versions of the CAVAT method – the Full method and the Quick method.

The Full method is recommended for use in decisions concerning individual trees or groups, when precision is required and sufficient time is available for a full assessment. The Quick method is intended as a strategic tool for management of the stock as a whole, as if it were a financial asset of the community. Valuation involves five steps, starting with determining a basic value for the tree based upon the tree's size (DBH) and a unit value factor - currently £15.88. The basic value is then adjusted according to the tree's i) location and accessibility by the general public, ii) vitality relative to that of a well-grown healthy tree of the same species , iii) amenity and suitability to the location, which may be either positive or negative, and iv) life expectancy.

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

Parks, residential and institutions were the land use types across Edinburgh with the greatest CAVAT value. Unsurprisingly these are also the areas with the highest percentage of large stature trees. By conserving maturing large stature trees in publicly accessible places such as parks (even cemeteries and highways) or in spaces where they can provide a sustainable urban drainage service (such as adjacent to wetland habitat, will help to ensure that the urban forest has high public amenity into the future. Preference should be given to large stature trees where possible, and to the selection of species with special amenity such as bark colour or canopy architecture. Selection should always be guided by local policy, diversity in planting for resilience, suitability to the soil type and it should be mindful of suitability to the location long term.

Avoided surface water runoff

The infrastructure required to remove surface water in urban environments is costly and is out-dated in many cities of the UK. This means that in large storm events or when water pipes fail surface water may not be removed quickly and damage to property can incur. Trees can ameliorate this problem by intercepting rainwater, retaining it on their leaves and absorbing some into their tissues for use in respiration. The roots of trees can also increase natural drainage and this is particularly important for stormwater amelioration where the surface around the trees is permeable allowing the water to infiltrate into the soil (although this is not calculated within i-Tree Eco). **The trees of Edinburgh intercept an estimated 183,730,743 litres of water per year**, equivalent to 33 times the volume of Edinburgh's 8-lane 50 m Royal Commonwealth Swimming Pool[10]. Based on the standard local rate charged for sewerage[11], this saves a quarter of a million pounds in avoided sewerage charges across Edinburgh each year (Table 6). By individual tree species, sycamore intercepts the most water (44.9 million litres per year), worth some £60,500 in avoided sewerage charges (Figure 16).

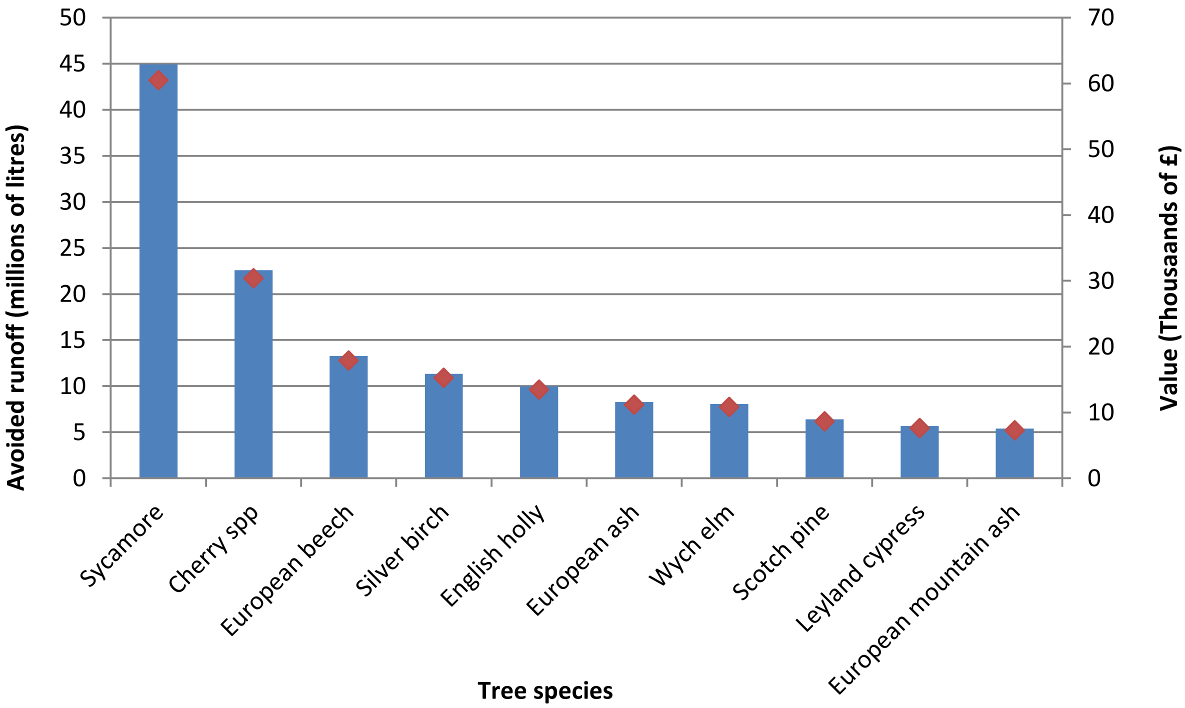


Figure 16. Avoided surface water runoff per year provided by urban trees in Edinburgh (columns) and their associated value in avoided sewer costs (diamonds).

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[10] Based upon the stated 5.5 million litres of water required to fill the pool http://www.edinburgh.gov.uk/news/article/837/royal_commonwealth_pool_splashes_back_into_action accessed August, 2016

[11] Based on Scottish Water's 2013/14 household volumetric waste water rate, charged per cubic metre. The rate used herein is £1.3464 per m^3. Using this value provides a conservative (under estimate) of savings as Scottish Water actually charge at £2.8471 for the first 23.75 m^3, and then at the rate of £1.3464 per m^3 for volumes after the first 23.75 m^3 (Scottish Water, 2013).

Table 6. Avoided Runoff for Trees in Edinburgh

Est. number of trees	711,979
Leaf area	73.9 km^2
Avoided runoff	183,730,743 litres per year
Avoided runoff value [10]	£247,375

Box 6. Rainfall interception by urban trees

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

With good design, the planting of large stature trees in areas prone to flooding can complement a planning authority's strategy against flooding. Planting should occur where there is appropriate planting space and species selection must be informed by preference to the local soil, climate and hydro-geological conditions. It should take account of tolerance to flooding, see for example Niinemets & Valladares (2006).

Planting for interception should also be complemented with planning for Sustainable Urban Drainage Systems (SUDS). SUDS are a sequence of management practices, control structures and strategies designed to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local water bodies (CIRIA, 2007). SUDS can actively incorporate trees in their design solution. The selection criteria must include all three elements of the SUDS principles: quality, quantity, and amenity (including biodiversity) in addition to the usual tree selection considerations including, for example, suitability to the location and its soil. Trees can provide a positive contribution to a SUDS system. Ultimately, however, tree use will depend on the local planning issues, water quality, water resources, architectural and landscape requirements, ecology and amenity issues, and the need to meet the requirements for the particular development.

Air Pollution Removal

Air pollution leads to a decline in human health, a reduction in the quality of ecosystems and it can damage buildings through the formation of acid rain (Table 7).

> In the United Kingdom, the government estimates that 29,000 people die each year as a result of air pollution and that the economic cost from the impacts of this air pollution is £9-19 billion every year (Defra, undated). If the pollutant gas NO2 is also considered, this figure is estimated to be as high as 60,000 deaths per year (The independent, 2014).

Trees and shrubs can mitigate the impacts of air pollution by directly reducing airborne pollutants. Trees absorb pollutants through their stomata, or simply intercept pollutants that are retained on the plant surface (Nowak et al. 2006). This leads to year-long benefits, with bark continuing to intercept pollutants throughout winter (Nowak et al. 2006). Plants also reduce local temperatures by providing shade and by transpiring (Bolund and Hunhammar, 1999), reducing the rate at which air pollutants are formed, particularly ozone (O_3; Jacob & Winner 2009). However, trees can also contribute to ozone production by emitting volatile organic compounds (VOC's) that react with other atmospheric pollutants such as nitrous oxide from 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).

Research indicates that, of the trees present in Edinburgh, oaks and sycamores have the potential to worsen air quality through release of VOC's. Whereas alder, ash and birch remove most pollutants, without substantially contributing to the formation of new pollutants (Stewart et al. 2002). i-Tree Eco takes the release of VOC's by trees into account to calculate the net difference in ozone production and removal.

Table 7. Urban pollutants, their health effects and sources.

Pollutant	Health effects	Source
NO_2	Shortness of breath Chest pains	Fossil fuel combustion: predominantly power stations (21%) and cars (44%)
O_3	Irritation to respiratory tract, particularly for asthma sufferers	From NO_2 reacting with sunlight
SO_2	Impairs lung function Forms acid rain that acidifies freshwater and damages vegetation	Fossil fuel combustion: predominantly burning coal (50%)
CO	Long term exposure is life threatening due to its affinity with haemoglobin	Carbon combustion under low oxygen conditions (e.g. in 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

It is estimated that **Edinburgh's urban forest removes 195 tonnes of airborne pollutants per year**, including NO_2, O_3, SO_2, CO and $PM_{2.5}$. Ozone (O_3) and NO_2 were the pollutants removed in the highest quantities. This demonstrates that although trees can increase ozone levels by producing VOC's, they remove more than they produce.

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 by slightly 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 8) because of the uncertainty associated with the value of removing some airborne pollutants, because the value of some pollutants (for example PM_{10}'s) can vary depending on their emission source or because the SDC has not yet been determined by the UK Government.

Using the UK system, which only includes NO_2 and SO_2 pollutants, **£575,313[12] worth of pollutants are removed annually from the atmosphere** (Table 8; Figure 17). Using the US valuation system, $831,044 million worth of pollutants are removed by urban trees in Edinburgh each year (Table 8). It is noteworthy here that previous versions of i-Tree Eco modelled the removal of PM_{10}s and $PM_{2.5}$; however, only $PM_{2.5}$ removal is considered by Eco version 6 as this is of considerably greater threat to human health than PM_{10}s.

[12] Using the lower "domestic" emission source for PM_{10}'s

Table 8. Amount of each pollutant removed by Edinburgh's urban forest and its associated value. USEC denotes United States Externality Cost and UKSDC denotes UK Social Damage Cost.

Pollutant	Mean amount removed/tonnes per annum	US value per tonne/$	USEC value/$	UK value per tonne/£	UKSDC value/£
CO	0.9	446	387	*n/a*	*n/a*
NO_2	39	6,835	264,634	14,646	567,034
O_3	144	3,143	453,840	*n/a*	*n/a*
$PM_{2.5}$	6.9	15,734	108,320	*n/a*	*n/a*
SO_2	4.2	913	3,864	1,956	8,279
Total	**195**		**831,044**		**575,313**

n/a = not available

The volume of airborne pollutants varied over the year, with a seasonal pattern evident in the removal of ozone, which was removed in higher volumes during spring and summer (Figure 18). This is because ozone is a product of the combination of NO_x, which was also removed in greater volumes in summer, and VOC's. The production of ozone is also more prevalent in warm temperatures (Sillman & Samson 1995). In addition, this creates a diurnal pattern, with ozone levels higher during the day than at night (Nowak, 2000).

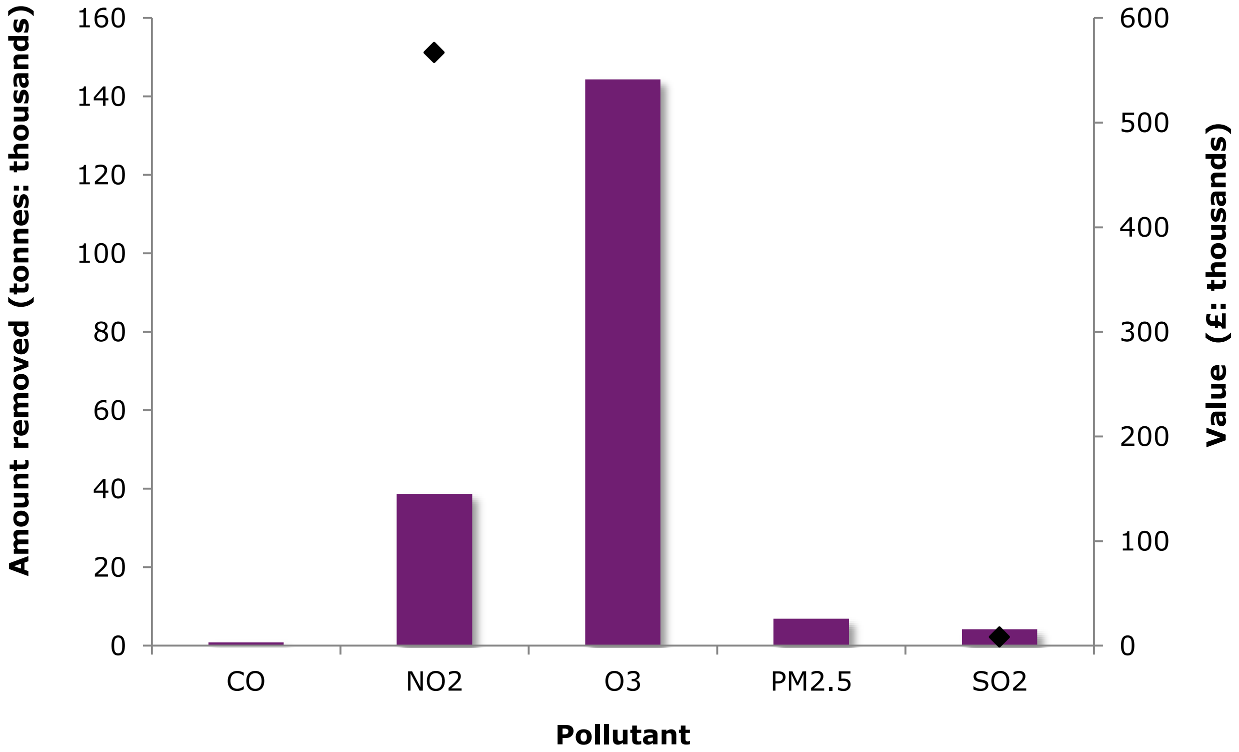


Figure 17. Mean quantity of pollutants removed by urban trees in Edinburgh (columns) and the associated value (diamonds; valued using UKSDC).

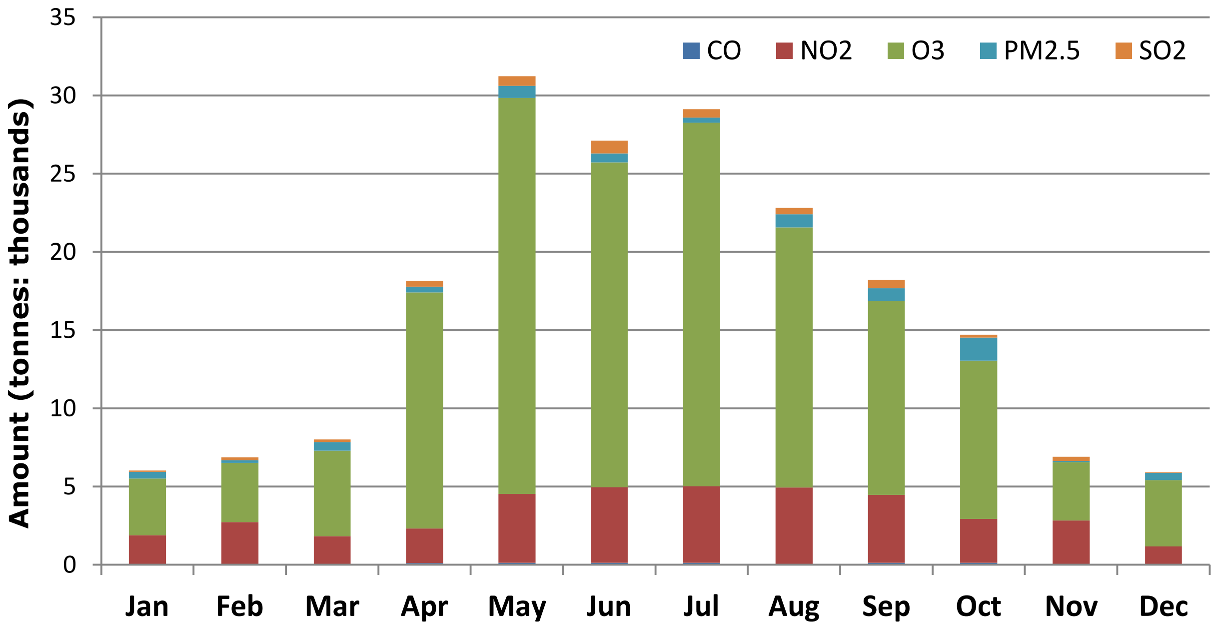


Figure 18. Amount of pollutants removed by Edinburgh's urban trees on a monthly basis.

Carbon Storage

It is estimated that **Edinburgh's trees store a total of 179,237 tonnes of carbon in their wood**, with sycamore storing the greatest amount (Figure 19). This is equivalent to **60%** of the annual carbon emissions produced by all the households in Edinburgh[13,14]. Alternatively, this is equivalent to the annual CO_2 emissions of **326,000**[15] **cars**, or almost twice (**180%**) the total estimated annual CO_2 emissions produced by all the cars owned in Edinburgh[12].

Similarly to leaf area, carbon storage depends not only on the number of trees present, but also their characteristics. In this case, the mass of a tree is important, as larger trees store more carbon in their tissues. Sycamore, for example, makes up 12% of Edinburgh's tree population, but is responsible for storing 34% of the total carbon stored in trees (the largest difference); common holly on the other hand, stores only 3% of carbon but makes up 11% of the tree population.

The carbon in trees can be valued within the framework of the UK government's carbon valuation method (DECC 2015). This is based on the cost of the fines that would be imposed if the UK does not meet carbon reduction targets. These values are split into two types, traded and non-traded. Traded values are only appropriate for industries covered by the European Union Emissions Trading Scheme. Tree stocks do not fall within this category so non-traded values are used instead. Within non-traded values, there are three pricing scenarios: low, central and

Carbon storage:

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

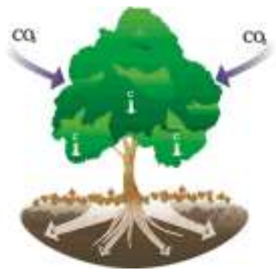
Carbon sequestration:

Estimated amount of carbon removed annually by trees:

Across a city, net carbon sequestration can be negative if emission from decomposition is greater than that sequestered by growing trees

Size matters:

Large trees are particularly important carbon stores and new plantings will help to ensure that current levels of forest cover are maintained or enhanced.



[13] Based on an average UK household emission of 5 tonnes of CO_2 per year in 2012 (Palmer & Cooper 2013)
[14] Based on the estimated number of households in Edinburgh in 2013 (www.nrscotland.gov.uk/files/statistics/council-area-data-sheets/city-of-edinburgh-factsheet.pdf)
[15] 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)
[12]Based on a population of 181,000 cars in Edinburgh (2011 Census data; ECC, 2014)

high. These reflect the fact that carbon value could change due to external circumstances, such as fuel price.

Based on the central scenario for non-traded carbon, **it is estimated that the carbon in the current tree stock is worth £39.8 million.** In 2050, this stock of carbon will be worth £83.0 million – this value assumes no change in the structure of the forest in terms of species assemblage, tree size or tree population size, and simply reflects the increased valued of non-traded carbon year-on-year to 2050. Appendix III. Non-traded values for carbon stored in Edinburgh's trees in all three valuation scenarios., outlines stored carbon value from 2013 until 2050 for all three pricing scenarios, again values do not take into account any changes that might occur to the urban forest of Edinburgh.

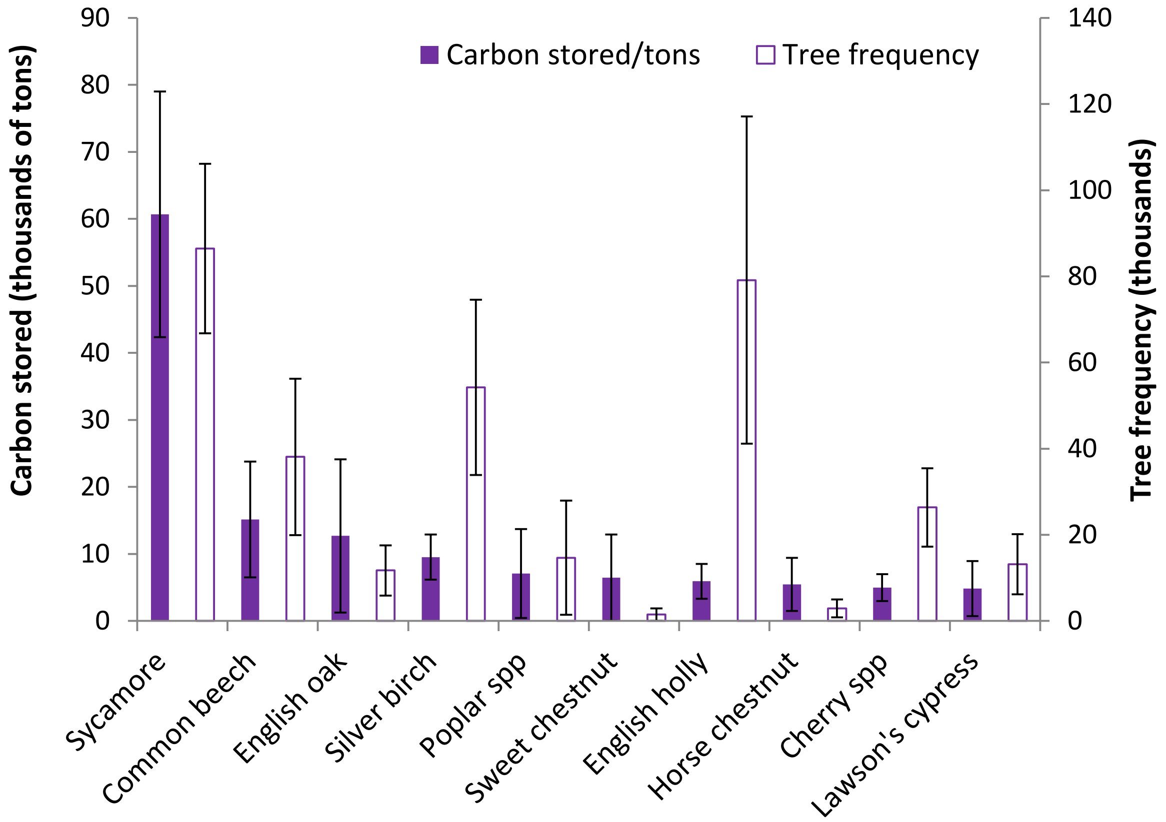


Figure 19. Amount of carbon stored in the Edinburgh urban forest and the frequency of each species. Only the ten trees with the highest storage rates are displayed. Error bars denote standard error of the mean (SEM).

Carbon Sequestration

The gross amount of carbon sequestered by the urban forest in Edinburgh each year is estimated at 5,628 tonnes. Taking into account the number of dead trees (net storage), which release carbon into the atmosphere, **the Edinburgh urban forest sequesters 4,885 tonnes of carbon per year net**; this **amount of carbon is estimated to be worth £1,063,109.** The net sequestration rate is equivalent to the annual emissions from **8,650 cars**[16]**,** or 5% of the number of cars in Edinburgh. It is also equivalent to the estimated annual emissions of 3,580 family homes (1.6% of the households in Edinburgh).

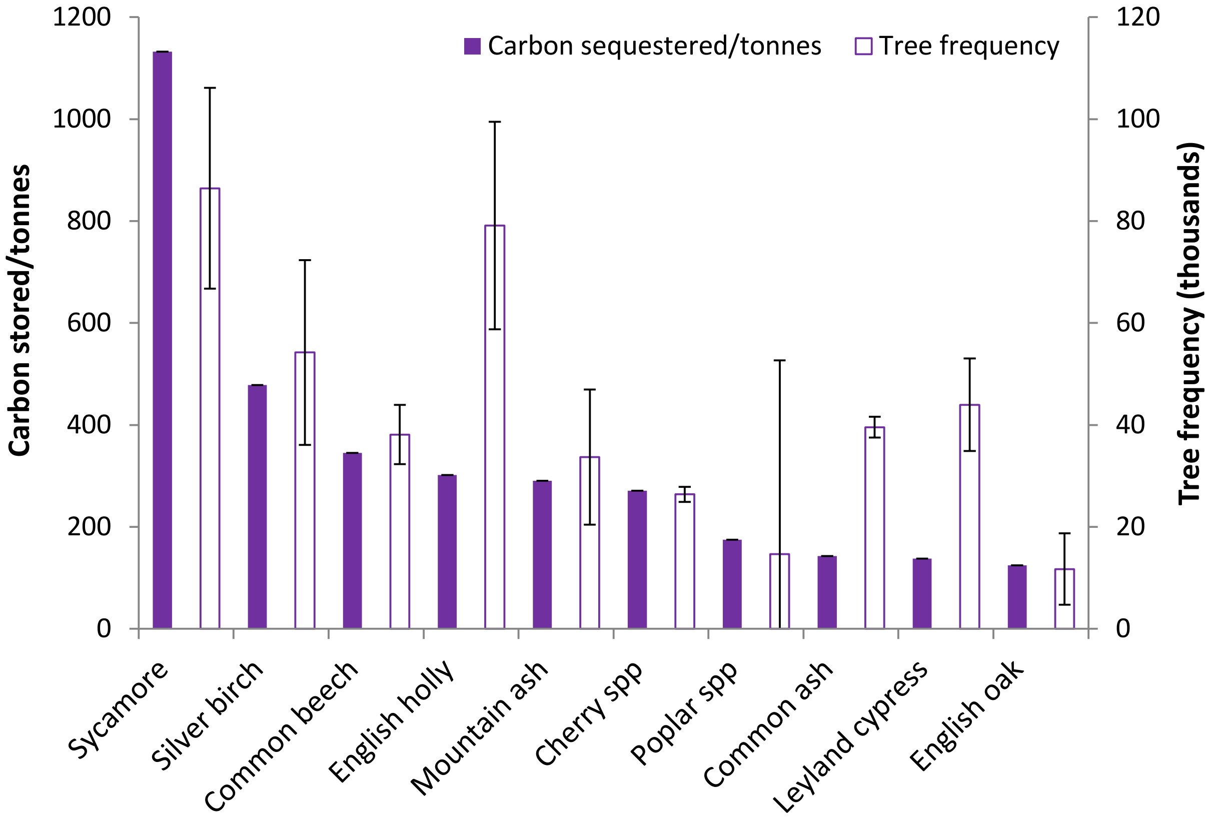


Figure 20. Carbon sequestered per year by the ten trees with highest rates, along with their frequency. Error bars denote standard error of the mean (SEM).

[16] Using the refs quoted in the 'Carbon Stored' chapter, above

Box 7. Carbon storage and annual 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 back into space. Carbon dioxide (CO2) 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 Edinburgh there is an over reliance on sycamore: at 12% of the tree population it holds 34% of the stored carbon. While the species specific growth rates of trees in the urban environment is still subject to research, sycamore also features as the main contributor to the annual sequestration of carbon by Edinburgh's urban forest. There is a risk in a single species contributing so much. Where other large stature trees – such as oak, tend to contribute to carbon storage in other UK cities they are generally absent in Edinburgh, leaving the carbon uptake ecosystem service of this urban forest vulnerable to the impacts of pests and disease.

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 Edinburgh's urban forest. This is because of these species 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, Liquidamber (American sweetgum), Ostrya, Pterocarrya and Zelkova, where suited to the location.

Habitat Provision

Trees and shrubs provide valuable habitat and food for many animal and plant species, from non-vascular plants, such as moss, to insects, birds and mammals. Two examples are included in this section to highlight some of the organisms that trees can support: i) the importance of trees/shrubs for supporting insects generally, and ii) the importance of trees/shrubs to pollinators. For a broader review see Alexander et al. (2006).

Pollinating insects provide ecosystem services by pollinating food crops, but they are under threat from pressures including land-use intensification and climate change (Vanbergen & The Insect Pollinators Initiative 2013). Providing food sources could help. Edinburgh's trees and shrubs are contributing to this food source, with sixteen of the tree species found in the Edinburgh survey supporting pollinating insects (RHS 2012) (Table 9b).

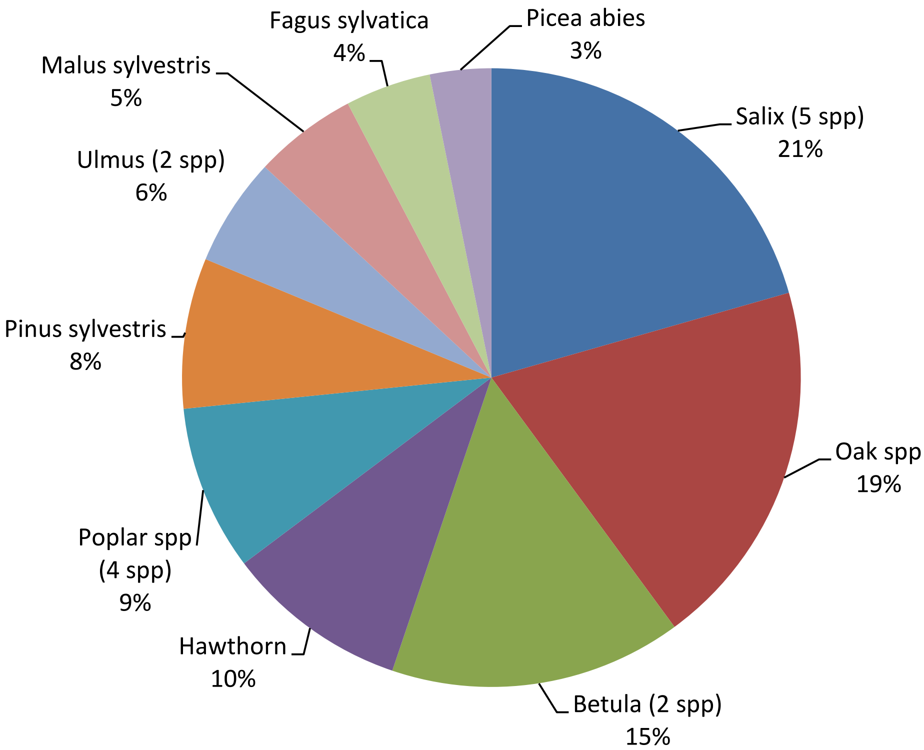


Figure 21. Relative importance of trees found in the Edinburgh survey for supporting insects. Where multiple tree species are denoted (in parentheses), insect species reflect the total associated with all hosts.

Many insect herbivores are supported by trees and shrubs. Some specialise on just a few tree species, whilst others are generalists that benefit from multiple tree and shrub species. Of the species found in the Edinburgh survey and for which insect data is available[17] willow and oaks support the most varied insect herbivore species (Figure 21). Beetles are also supported by these species, however they are better supported by Scots pine (Table 10). This highlights that though some species have fewer insects associated with them they are extremely important for certain groups.

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

Table 9. Trees encountered in Edinburgh that are beneficial to pollinators (RHS, 2012) presented by (a) genus and (b) species

(a) Genus	Season
Acer spp	Spring
Aesculus spp	Summer
Malus spp	Spring
Prunus spp	Spring
Salix spp	Spring
Sorbus spp	Summer

(b) Species	Season
Apple, common	Spring
Cherry laurel	Spring
Common plum	Spring
Field maple	Spring
Goat willow	Spring
Hawthorn, common	Summer
Holly, common	Spring, Summer
Laurel de olor	Summer
Lime, small-leafed	Summer
Lime, large-leafed	Summer
Norway maple	Spring
Rowan, common	Summer
Sedum spp	Spring
Sycamore	Spring
Whitebeam	Summer
Wild cherry	Spring

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

Box 8. Habitat provision by urban trees

Trees and shrubs provide valuable habitat and food for many animal and plant species. Data availability on the role that each tree and shrub species has in supporting biodiversity found in the urban environment is far from comprehensive. However, over-arching principles such as native trees and shrubs association with more faunal species than non-natives, can be used to plan for an urban forest that complements local biodiversity. Similarly, preferential planting of species identified in Tables 10a and 10b could be encouraged amongst private as well as public land owners. For example, local residents can be encouraged to play their part through education and awareness raising publications by the RHS, RSPB and others on gardening for wildlife.

Recent research has shown that exotic plants can extend the flowering season and provide additional resources to pollinators when the abundance of flowers on native and near-native plants was low. In addition, interactions between an exotic plant and some pollinators suggest that exotic plant species can be especially valuable to some insect species. Therefore, selecting trees from one region of origin may not be the optimal strategy for providing resources for pollinating insects in urban landscapes. It seems that the best advice is to encourage the planting of a variety of trees in Edinburgh 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).

Table 10. Numbers of insect species supported by tree species (a) encountered in the Edinburgh survey and (b) for other commonly found urban tree species which data is available#. Brightest green boxes denote tree species supporting the most insects and red denote the lowest number. Middle values are represented by a gradient between the two.

(a) Species	Scientific name	Total	Beetles	Flies	True bugs	Wasps, sawflys	Moths and butterflies	Other
Willow spp	Salix (5 spp)	450	64	34	56	104	162	9
Oak spp	Quercus robur & Quercus petraea	423	67	7	81	70	189	9
Birch spp	Betula (2 spp)	334	57	5	30	42	179	9
Hawthorn	Crataegus monogyna	209	20	5	40	12	124	8
Poplar spp	Populus (4 spp)	189	32	14	42	29	69	3
Scots pine	Pinus sylvestris	172	87	2	25	11	41	6
Elm spp	Ulmus (2 spp)	124	15	4	22	6	55	11
Crab apple	Malus sylvestris	118	9	4	12	2	71	2
Common beech	Fagus sylvatica	98	34	6	11	2	41	4
Norway spruce	Picea abies	70	11	3	14	10	22	1
Common ash	Fraxinus excelsior	68	1	9	7	7	25	9
Rowan	Sorbus aucuparia	58	8	3	6	6	33	2
Lime spp	Tilia (2 spp)	57	3	5	14	2	25	8
Sycamore	Acer pseudoplatanus	43	2	3	11	2	20	5
Fir spp	Abies	11	8	0	0	0	3	0
Sweet chesnut	Castanea sativa	11	1	0	1	0	9	0
Holly	Ilex aquifolium	10	4	1	2	0	3	0
Horse chestnut	Aesculus hippocastanum	9	0	0	5	0	2	2
English yew	Taxus baccata	6	0	1	1	0	3	1

(b) Species	Scientific name	Total	Beetles	Flies	True bugs	Wasps, sawflys	Moths and butterflies	Other
Blackthorn	Prunus spinosa	153	13	2	25	7	91	11
European alder	Alnus glutinosa	141	16	3	32	21	60	9
Common hazel	Corylus avellana	106	18	7	19	8	48	6
European hornbeam	Carpinus betulus	51	5	3	10	2	28	2
Field maple	Acer campestre	51	2	5	10	2	24	6
European larch	Larix decidua	38	6	1	9	5	16	1
Common juniper	Juniperus communis	32	2	5	1	1	15	2
Walnut	Juglans regia	7	0	0	2	0	2	3
Holly oak	Quercus ilex	5	0	0	1	0	4	0
Black locust	Robinia pseudoacacia	2	0	0	1	1	0	0

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

Risks of Pests and Disease

Pests and diseases are a serious threat to urban forests. Severe outbreaks have occurred within living memory, with Dutch Elm Disease killing approximately 30 million trees in the UK (Webber 2010). Climate change may exacerbate this problem, ameliorating the climate for some pests and diseases, making outbreaks more likely (Forestry Commission 2014). Assessing the risk pests and diseases pose to urban forests is, therefore, of paramount importance. 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 Edinburgh on a single genus (Table 11) and for multiple genera (Table 12).

Table 11. Risk matrix used for the probability of a pest or disease becoming prevalent in the Edinburgh urban forest on a single genus (one or more species).

Prevalence	% Population		
	0-5	6-10	>10
Not in UK	Green	Amber	Amber
Present in UK	Amber	Amber	Red
Present in Scotland	Amber	Red	Red

Table 12. Risk matrix used for the probability of a pest or disease becoming prevalent in the Edinburgh urban forest on multiple genera.

Prevalence	% Population		
	0-25	26-50	>50
Not in UK	Green	Amber	Amber
Present in UK	Amber	Amber	Red
Present in Scotland	Amber	Red	Red

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 Edinburgh. Threats not yet present in the UK, such as Asian longhorn beetle, pose a threat to many species and could potentially devastate a diverse range of urban trees. UK wide initiatives such as plant health restrictions are designed to combat these threats, but many pests are difficult to detect (Forestry Commission 2014). In order to protect urban forests from all pests and diseases, vigilance is key. Monitoring urban trees for signs of pests and diseases helps fast responses to eradicate pests before they are a problem and informs research targeted at combating diseases in the long term.

Table 13 gives an overview of the current and emerging pest and diseases that could affect Edinburgh'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 VII – Pests and Diseases. The tables present the population of the urban forest of Edinburgh 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 for the presence and spread of a pest or disease, and strategies to manage the risks that they pose.

Healthy trees

Ash dieback – Chalara fraxinea – 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 should 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.

Table 13. Risks of emerging pests and diseases

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in Scotland	Risk of spreading to Scotland	Population at risk (%)	CAVAT value of sampled trees (£)	Stored carbon value trees(£)
Acute oak decline	*Quercus robur, Q. petraea*	SE England and Midlands	None	Medium risk – slow spreading	**3.5%**	130,717	3,291,231
Asian longhorn beetle	Many broadleaf species (see Appendix IV)	None (previous outbreaks contained)	None	Medium risk – climate may be suitable	**59.3%**	1,400,906	27,873,245
Chalara dieback of ash	*Fraxinus excelsior, F. angustifolia*	Cases across the UK	Confirmed cases in Scotland	High - already present	**5.6%**	51,730	1,070,631
Emerald ash borer	*F. excelsior, F. angustifolia*	None	None	Medium risk (imported wood)	**5.6%**	51,730	1,070,631
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	**24.3%**	542,365	10,790,521
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	**20.2%**	504,755	12,442,376
Oak processionary moth	*Quercus* spp.	Southern England	None	Medium, small colonies are containable	**4.1%**	183,680	3,894,909

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in Scotland	Risk of spreading to Scotland	Population at risk (%)	CAVAT value of sampled trees (£)	Stored carbon value trees(£)
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 Scotland	High – already present	**5.8%**	192,304	7,619,273
Phytophthora kernoviae	*F. sylvatica, Ilex aquifolium, Q. robur, Q. ilex*ǂ	Mainly SW England and Wales	Two locations in Scotland	High – already present	**18.1%**	349,899	5,202,793
Phytophthora alni	*Alnus* spp.	Riparian ecosystems in the UK	Present on Scottish river systems	High – already present	**2.7%**	3,612	50,672
Dothistroma (red band) needle blight	*Pinus nigra ssp. laricio, P. contorta var. latifolia, Pinus sylvestris*	Several UK sites	Throughout Scotland	High – already present	**4.5%**	95,215	846,414
Spruce bark beetle	*Picea* spp.	Mainly W England and Wales	Southern Scotland	High – already present	**0.8%**	18,521	151,309

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

Conclusions

The urban forest of Edinburgh provides valuable ecosystem services and improves the quality of life for local residents, making it a significant asset to the area. Edinburgh is estimated to contain more than 712,000 trees, with a tree density of 62 per hectare, which is comparable to the UK average. Large diameter trees accounted for just 6% of the trees surveyed with institutional land and parks containing the highest proportion of large trees; residential and agricultural land were the next most important reserves of large trees. Large diameter trees are important because they tend to deliver more ecosystem services and provide more habitat for wildlife. Ten-percent of trees surveyed were however medium sized trees with a 40-60 cm diameter, suggesting that the proportion of large trees believed to be indicative of a resilient forest can be reached in the short term with prudent protection and management.

The ecosystem services provided by trees are on-going and, for services such as carbon storage, could become more valuable in the future as external factors change. Planning tree stocks to maintain a high level of ecosystem service delivery is, therefore, of paramount importance. A total of 50 tree and shrub species were identified in the survey. Species diversity, important for ensuring the resilience of urban trees against pests and diseases, was lower than that from other UK i-Tree Eco surveys (e.g. 88 different species were identified in the Tawe catchment area of S Wales) and so could be improved upon. The twelve most abundant tree species in Edinburgh accounted for 70.8% of the population, and the proportions of the two most common species (sycamore and common holly) exceeded the recommended limit of 10% abundance. This implies that planning for the urban forest of Edinburgh is required to make it more diverse and resilient to future changes.

Diversity was highest on residential land and in parks, associated with highest abundance of trees. Edinburgh could improve the diversity of the urban forest by targeting areas with lower diversity. Many of these, such as commercial or vacant land can be influenced by local policy, easing this process.

Scotland has been, so far, less hit by pest and diseases than England and Wales, but with climate change predicting higher air temperatures across the UK many of the pests and diseases already established in the south may move northward. Some of these, such as *Phytophthora* spp and more recently Chalara ash dieback, have been already identified in Scotland and contribute to a fair number of casualties. Medium risk (due to climate) but high impact pests such as the Asian longhorn beetle, although not currently present in the UK as outbreaks have been contained, could affect many of the trees of Edinburgh. Planning an urban forest that is resilient to a broad range of pests and diseases is key, this will be aided by maintaining high tree diversity across Edinburgh taking into account trees on private property in addition to those in the public realm.

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

The net carbon sequestered annually by Edinburgh's trees was 4,885 tonnes. This information and the other values for the benefits of trees highlighted in this report can be used to shape policy or local targets for protecting existing trees and encouraging the expansion of the urban forest. The annual carbon sequestration by trees can be compared to carbon emitting practices, such as annual emissions by homes within Edinburgh, and could then be used to inform tree planting to offset a proportion of the CO_2 emissions. In this way, tangible goals can be incorporated into local policy.

i-Tree Eco does have limitations. Not all benefits provided by trees could be quantified, including the calming effect that trees have on noise pollution and their ability to cool the urban environment. The urban forest in Edinburgh is therefore more valuable than stated in this report. Future developments in i-Tree Eco will enable these extra benefits to supplement this report in the future, giving a more comprehensive picture.

This study is also limited given that it is a snapshot of the urban forest back in 2011. Monitoring, using the same or a comparable technique, will allow variations to be taken into account and in the long term could be used to illustrate dynamic processes such as climate change and allow a robust long-term picture to be built. It is recommended that an i-Tree Eco survey is conducted every 5-10 years to support the management and planning of Edinburgh's urban forest.

Edinburgh's urban forest considerably improves the lives of inhabitants and visitors and should be valued as an asset in line with other beneficial infrastructure projects, such as roads, drainage and energy infrastructure. The urban forest provides functional services that help keep urban spaces pleasant, even sustainable, places to live. Planning and policy could reflect this, valuing trees as an integral part of the urban landscape.

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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 and Crane, 2000), 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.

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.

In the original study (2011) data for impervious area was not collected. Therefore, a desk based technique was employed to estimate impervious area, which is required to calculate avoided surface water runoff. Each plot was mapped using Ordnance Survey Master Map (OS MM). Using the guidelines from the Communities and Local Government

(2009)[18] OS MM was remapped to the Generalised Land Use Database (GLUD) classification. Each GLUD category having been assigned a permeability category based on its dominant characteristics (see table below). Figure 22 shows a single i-Tree Eco plot for Edinburgh classified into GLUD categories.

Ordnance Survey Master Map Variable				
Theme	**Make**	**Descriptive group**	**GLUD**	**Permeability**
Buildings	Manmade	Building	Buildings	Non-Permeable
Land	Manmade	General Surface	Other	Non-Permeable
Land	Multiple	General Surface	Gardens	Permeable
Land	Natural	General Surface	Greenspace	Permeable
Land	Natural	Natural Environment	Greenspace	Permeable
Land	Unclassified	Unclassified	Other	Non-Permeable
Rail	Manmade	Rail	Rail	Non-Permeable
Rail	Natural	Rail	Rail	Permeable
Roads Tracks And Paths	Manmade	Path	Path	Non-Permeable
Roads Tracks And Paths	Manmade	Road Or Track	Road	Non-Permeable
Roads Tracks And Paths	Manmade	Roadside	Road	Non-Permeable
Roads Tracks And Paths	Natural	Road Or Track	Other	Permeable
Roads Tracks And Paths	Natural	Roadside	Road	Permeable
Water	Natural	Inland Water	Water	Permeable

[18] Communities and Local Government (2009) Generalised Land Use Database. Update 2006. https://www.thenbs.com/PublicationIndex/documents/details?Pub=DCLG&DocId=288695

Figure 22. A single i-Tree Eco plot for Edinburgh classified into GLUD categories.

The results from the desk based assessment of impervious area were Quality Assured (QA) by manually assessing 25% of the plots using aerial photography. Where a polygon contained multiple categories the dominant land use/permeability was used. Where the correct category could not be determined, due to size or obstructions, an "Unknown" classification was assigned. Our QA process found that 96% of GLUD categories and 90% of permeability categories had been assigned correctly (see table below). Only 1.3% of GLUD land use categories were judged to be incorrect; this may reflect changes between the date of OS MM mapping and aerial photography. However 6.3% of permeability classifications were considered incorrect. The most common cause being front gardens having been covered by concrete of similarly impervious structures for parking or pathways.

	GLUD	Permeability
Attribution correct	96.2%	89.9%
Attribution incorrect	1.3%	6.3%
Unknown	2.5%	3.8%

Next the impervious area under trees had to be determined. For each tree its canopy dimensions were used to create an 'idealised' circular canopy. This canopy was then compared with our permeability categories to determine the area of impervious surface under each canopy. Values for impervious surface area under canopy ranged from 0%-83%; the average impervious surface area under canopy was 5.13%. The data was added to the i-Tree project and submitted in i-Tree Eco Version 6 to calculate the volume of precipitation intercepted by Edinburgh's urban trees.

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

However, this 'avoided charges' cost is a conservative estimate of the total 'avoided charges' across the full survey area as it does not account for infrastructural, operational and treatment charges linked to surface water management by, for example, Local Authorities, Internal Drainage Boards and Natural Resources Wales. Therefore, the Standard volumetric rate – Surface water rebated per cubic metre value of £1.3238 was used as a representative value of the avoided cost of treating surface water runoff across the whole survey area in i-Tree Eco studies conducted in Wales in 2014/15. Consequently, the comparable Volumetric Waste Water Charge of £1.3464 is used in this Edinburgh i-Tree Eco, noting however that this value is in itself a conservative estimate as Scottish Water actually charge at £2.8471 for the first 23.75 m^3 and then at the rate of £1.3464 per m^3 for volumes after the first 23.75 m^3 (Scottish Water, 2013).

Table 14. Land use definitions (adapted from the i-Tree Eco v5 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 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, 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year *x*) to estimate tree diameter and carbon storage in year *x+1*.

Calculating air pollution removal: estimates are derived from calculated hourly tree-canopy resistances for ozone and sulphur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi, 1988; Baldocchi et al., 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser, 1972;

Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal 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 Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information (Nowak et al., 2002), in this case 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.

In the UK, however, the appropriate way to monetise the carbon sequestration benefit is to multiply the tonnes of carbon stored by the non-traded price of carbon (i.e. this carbon is not part of the EU carbon trading scheme). The non-traded price is not based on the cost to society of emitting the carbon, but is based on the cost of not emitting the tonne of carbon elsewhere in the UK in order to remain compliant with the Climate Change Act. The unit values used were based on those given in DECC (2015). This approach gives higher values of carbon than the approach used in the United States, reflecting the UK Government's response to the latest science, which shows that deep cuts in emissions are required to avoid the worst effects of climate change.

Official pollution values for the UK are based on the estimated social cost of the pollutant in terms of impact upon human health, damage to buildings and crops. 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

An amended CAVAT full method was chosen to assess the trees in this study, in conjunction with the creator of the system. Although the alternative "quick" method is designed to be used in conjunction with street tree surveys as an aid to asset management of the tree stock as a whole (taking marginally less time to record) it was considered that the greater precision of the full method, in addition to the fact that trees other than street trees were assessed, was more appropriate in the current 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 Edinburgh 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 Importance List

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

Rank	Species	Population (%)	Leaf Area (%)	Importance Value
1	Sycamore	12.1%	24.5%	36.6
2	Common holly	11.1%	5.4%	16.5
3	Silver birch	7.6%	6.2%	13.8
4	Leyland cypress	6.2%	3.1%	9.3
5	Common ash	5.6%	4.5%	10.1
6	Common beech	5.3%	7.2%	12.6
7	Rowan	4.7%	2.9%	7.7
8	Scots pine	4.5%	3.5%	8.0
9	Wych elm	4.5%	4.4%	8.9
10	Cherry spp	3.7%	12.3%	16.0
11	Elder	3.1%	0.6%	3.7
12	Red alder	2.3%	0.3%	2.6
13	Cherry laurel	2.3%	0.9%	3.1
14	Poplar spp	2.1%	1.2%	3.2
15	Birch spp	1.9%	0.4%	2.2
16	Lawson's cypress	1.9%	1.0%	2.9
17	Sessile oak	1.9%	0.8%	2.7
18	Mountain ash	1.9%	0.6%	2.4
19	Hawthorn	1.6%	0.7%	2.3
20	Apple spp	1.6%	1.0%	2.6
21	Cherry plum	1.6%	0.9%	2.5
22	English oak	1.6%	1.7%	3.4
23	Golden chain tree	1.2%	0.3%	1.5
24	Large-leaved lime	1.0%	1.3%	2.4
25	Norway spruce	0.8%	0.6%	1.5
26	Small-leaved lime	0.8%	1.7%	2.5
27	Common lime	0.8%	0.4%	1.2
28	Indian paper birch	0.6%	0.2%	0.8
29	Norway maple	0.4%	2.0%	2.4
30	Horsechestnut	0.4%	1.3%	1.7
31	White poplar	0.4%	0.1%	0.5
32	European aspen	0.4%	0.2%	0.6
33	Lime spp	0.4%	1.6%	2.1
34	Fir spp	0.2%	0.8%	1.0
35	Alder spp	0.2%	0.0%	0.2
36	Green alder	0.2%	0.3%	0.5
37	Beggarticks spp	0.2%	0.0%	0.2
38	Sweet chestnut	0.2%	1.3%	1.5
39	Ash spp	0.2%	0.3%	0.5
40	Golden chain tree spp	0.2%	0.0%	0.2
41	Glossy privet	0.2%	0.0%	0.2
42	European crabapple	0.2%	0.2%	0.4

43	Sweet cherry	0.2%	0.8%	1.0
44	Oak spp	0.2%	0.2%	0.4
45	Scarlet oak	0.2%	0.7%	0.9
46	Northern red oak	0.2%	0.6%	0.8
47	Willow spp	0.2%	0.3%	0.5
48	English yew	0.2%	0.1%	0.3
49	Silver-leaved lime	0.2%	0.1%	0.3
50	Elm spp	0.2%	0.5%	0.7

Appendix III. Non-traded values for carbon stored in Edinburgh's trees in all three valuation scenarios.

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

						Non-traded unit value (£/tCO2e)					Value of discounted stored (£/tCO2e)		
	Year	Stored C (t)	Net sequestered C (t)	Stored C (tCO2e)	Net sequestered C (tCO2e)	Low	Central	High	Discount rate	Discount factor	Low	Central	High
1	2013	179,237	4,886	657,203	17,914	30	61	91	3.5	1.00	19,909,450	39,818,901	59,728,351
2	2014	184,123	4,886	675,117	17,914	31	61	92	3.5	0.97	20,032,363	40,064,727	60,097,090
3	2015	189,009	4,886	693,031	17,914	31	62	94	3.5	0.93	20,141,843	40,283,686	60,425,530
4	2016	193,894	4,886	710,945	17,914	32	63	95	3.5	0.90	20,238,390	40,476,780	60,715,170
5	2017	198,780	4,886	728,859	17,914	32	64	96	3.5	0.87	20,322,488	40,644,976	60,967,464
6	2018	203,666	4,886	746,774	17,914	33	65	98	3.5	0.84	20,394,608	40,789,216	61,183,824
7	2019	208,551	4,886	764,688	17,914	33	66	99	3.5	0.81	20,455,206	40,910,412	61,365,618
8	2020	213,437	4,886	782,602	17,914	34	67	101	3.5	0.78	20,504,725	41,009,450	61,514,174
9	2021	218,323	4,886	800,516	17,914	34	68	103	3.5	0.75	20,577,327	41,154,654	61,731,980
10	2022	223,208	4,886	818,430	17,914	35	69	104	3.5	0.73	20,634,298	41,268,596	61,902,893
11	2023	228,094	4,886	836,344	17,914	35	71	106	3.5	0.70	20,676,133	41,352,266	62,028,399
12	2024	232,979	4,886	854,258	17,914	36	72	108	3.5	0.68	20,703,330	41,406,661	62,109,991
13	2025	237,865	4,886	872,172	17,914	36	73	109	3.5	0.65	20,716,388	41,432,776	62,149,164
14	2026	242,751	4,886	890,086	17,914	37	74	111	3.5	0.63	20,715,804	41,431,608	62,147,412
15	2027	247,636	4,886	908,000	17,914	38	75	113	3.5	0.61	20,702,076	41,404,152	62,106,227
16	2028	252,522	4,886	925,914	17,914	38	76	114	3.5	0.59	20,675,697	41,351,394	62,027,091
17	2029	257,408	4,886	943,829	17,914	39	77	116	3.5	0.57	20,637,158	41,274,316	61,911,474
18	2030	262,293	4,886	961,743	17,914	39	78	118	3.5	0.55	20,586,945	41,173,891	61,760,836
19	2031	267,179	4,886	979,657	17,914	43	86	129	3.5	0.53	22,115,546	44,231,093	66,346,639

20	2032	272,065	4,886	997,571	17,914	47	93	140	3.5	0.51	23,578,244	47,156,488	70,734,732
21	2033	276,950	4,886	1,015,485	17,914	50	100	150	3.5	0.49	24,975,457	49,950,915	74,926,372
22	2034	281,836	4,886	1,033,399	17,914	54	108	161	3.5	0.47	26,307,739	52,615,478	78,923,216
23	2035	286,722	4,886	1,051,313	17,914	57	115	172	3.5	0.46	27,575,761	55,151,521	82,727,282
24	2036	291,607	4,886	1,069,227	17,914	61	122	183	3.5	0.44	28,780,303	57,560,606	86,340,909
25	2037	296,493	4,886	1,087,141	17,914	65	129	194	3.5	0.43	29,922,244	59,844,487	89,766,731
26	2038	301,379	4,886	1,105,055	17,914	68	137	205	3.5	0.41	31,002,546	62,005,093	93,007,639
27	2039	306,264	4,886	1,122,969	17,914	72	144	216	3.5	0.40	32,022,253	64,044,506	96,066,758
28	2040	311,150	4,886	1,140,883	17,914	76	151	227	3.5	0.38	32,982,472	65,964,945	98,947,417
29	2041	316,036	4,886	1,158,798	17,914	79	159	238	3.5	0.37	33,884,375	67,768,749	101,653,124
30	2042	320,921	4,886	1,176,712	17,914	83	166	249	3.5	0.36	34,909,125	69,818,250	104,727,375
31	2043	325,807	4,886	1,194,626	17,914	87	173	260	3.0	0.35	35,887,176	71,774,351	107,661,527
32	2044	330,693	4,886	1,212,540	17,914	90	180	271	3.0	0.34	36,819,048	73,638,095	110,457,143
33	2045	335,578	4,886	1,230,454	17,914	94	188	282	3.0	0.33	37,705,314	75,410,628	113,115,942
34	2046	340,464	4,886	1,248,368	17,914	98	195	293	3.0	0.32	38,546,594	77,093,188	115,639,782
35	2047	345,350	4,886	1,266,282	17,914	101	202	303	3.0	0.31	39,343,549	78,687,099	118,030,648
36	2048	350,235	4,886	1,284,196	17,914	105	210	314	3.0	0.30	40,096,880	80,193,760	120,290,639
37	2049	355,121	4,886	1,302,110	17,914	108	217	325	3.0	0.29	40,807,319	81,614,638	122,421,958
38	2050	360,007	4,886	1,320,024	17,914	112	224	336	3.0	0.28	41,475,631	82,951,263	124,426,894

Calculation notes: the total amount of carbon stored and the annual sequestration rates are calculated to a baseline year of 2013.

Appendix VII – Pests and Diseases

Acute Oak Decline

Acute oak decline (AOD) affects mature trees (>50 years old) of both native oak species (common oak and sessile oak). Over the past four years, the reported incidents of stem bleeding, a potential symptom of AOD, have been increasing. The incidence of AOD in Britain is un-quantified at this stage but estimates put the figure at a few thousand affected trees. The condition seems to be most prevalent in the Midlands and the South East of England as far west as Wales. So far there are no confirmed cases on in Scotland and as the disease spreads slowly acute oak decline poses a medium risk to the Edinburgh'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.

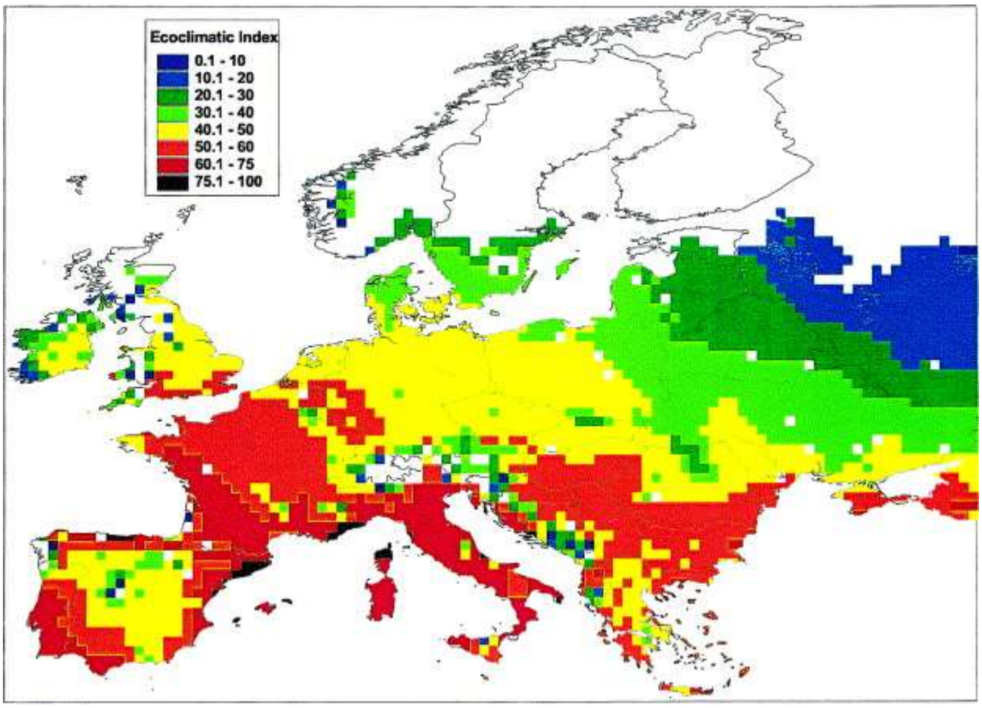

Figure 23. Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB (Ref: MacLeod *et al.,* 2002).

In March 2012 an ALB outbreak was found in Maidstone, Kent. The Forestry Commission and Fera removed more than 2, 000 trees from the area to contain the outbreak. No further outbreaks have been reported in the UK. Analysis of climate data suggests that some warmer coastal areas of Scotland are suitable for beetle establishment, but southeast England and the south coast are at greatest risk. MacLeod, Evans & Baker (2002) modelled climatic suitability for outbreaks based on outbreak data from China and the USA and suggested that CLIMEX (the model used) Ecoclimatic Indices of >32 could be suitable habitats for ALB. Figure 23 suggests that Edinburgh may be vulnerable to ALB under this model.

If an ALB outbreak did occur in Edinburgh it would pose a significant threat to 59.3% of the trees, not including attacks on shrub species

The known host tree and shrub species include:

Acer spp. (maples and sycamores)

Aesculus spp. (horse chestnut)

Albizia spp. (Mimosa, silk tree)

Alnus spp. (alder)

Betula spp. (birch)

Carpinus spp. (hornbeam)

Cercidiphyllum japonicum (Katsura tree)

Corylus spp. (hazel)

Fagus spp. (beech)

Fraxinus spp. (ash)

Koelreuteria paniculata

Platanus spp. (plane)

Populus spp. (poplar)

Prunus spp. (cherry, plum)

Robinia pseudoacacia (false acacia/black locust)

Salix spp. (willow, sallow)

Sophora spp. (Pagoda tree)

Sorbus spp. (mountain ash/rowan, whitebeam etc)

Quercus palustris (American pin oak)

Quercus rubra (North American red oak)

Ulmus spp. (elm)

Chalara Dieback of Ash

Ash dieback, caused by the fungus *Hynenoscyphus fraxineus*, targets common and narrow leaved ash. Young trees are particularly vulnerable and can be killed within one growing season of symptoms becoming visible. Older trees take longer to succumb, but can die from the infection after several seasons. *H. fraxinea* was first recorded in the UK in 2012 in Buckinghamshire and has now been reported across the UK, including in urban areas. Scotland has several confirmed cases of the disease. Ash dieback poses a threat to 5.6% of Edinburgh'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 30-40km 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 5.6% of Edinburgh's urban forest.

Giant Polypore

Giant polypore (*Meripilus giganteus)* is a fungus that can cause internal decay in trees without any external symptoms (Schmidt 2006), causing trees to potentially topple or collapse (Adlam 2014). It is particularly common in urban areas and can also cause defoliation and crown dieback (Schmidt 2006; Adlam 2014). Giant polypore predominantly affects hardwoods such as horse chestnut, beech, cherry, mountain ash and oak. 24.3% of Edinburgh's urban forest could be vulnerable to giant polypore.

Gypsy Moth

Gypsy moth (GM), *Lymantria dispar*, is an important defoliator of a very wide range of trees and shrubs in mainland Europe, where it periodically reaches outbreak numbers. It can cause tree death if successive, serious defoliation occurs on a single tree. A small colony has persisted in northeast London since 1995 and a second breeding colony was found in Aylesbury, Buckinghamshire in the summer of 2005. Aside from these disparate colonies, GMs range in Europe does not reach as far North as the UK. Some researchers suggest that the climate in the UK is currently suitable for GM should it arrive here and that it would become more so if global temperatures rise (Vanhanen *et* al., 2007). However, the spread of gypsy moth in the USA has been slow, invading less than a third of its potential range (Morin *et al*., 2005). If GM spread to Scotland, it would pose a threat to 20.2%of Edinburgh's urban trees.

Oak Processionary Moth

Established breeding populations of oak processionary moth (OPM) have been found in South and South West London and in Berkshire. It is thought that OPM has been spread on nursery trees. The outbreak in London is now beyond eradicating, whereas efforts to stop the spread out of London and to remove those in Berkshire are underway. The caterpillars cause serious defoliation of oak trees, their principal host, but the trees will recover and leaf the following year. On the continent, they have also been associated with hornbeam, hazel, beech, sweet chestnut and birch, but usually only where there is heavy infestation of nearby oak trees. The caterpillars have urticating (irritating) hairs that carry a toxin that can be blown in the wind and cause serious irritation to the skin, eyes and bronchial tubes of humans and animals. They are considered a significant human health problem when populations reach outbreak proportions, such as those in The Netherlands and Belgium have done in recent years. Oak processionary moth poses a threat to 4.1% of Edinburgh's urban forest.

Phytophthora ramorum

Phytophthora ramorum was first found in the UK in 2002 and primarily affects species of oak (Turkey oak, Red oak and Holm oak), beech and sweet chestnut. However, it has also been known to occasionally infect European and hybrid larch and kills Japanese larch. Rhododendron is a major host, which aids the spread of the disease. Many cases have been identified in Scotland. *Phytophthora ramorum* poses a threat to 5.8% of Edinburgh'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. PK has been found at two locations in Scotland. *Phytophthora kernoviae* is deemed to pose a risk to 18.1% of Edinburgh'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 l alder populations that occur along Scottish rivers. *Phytophthora alni* poses a threat to 2.7% of Edinburgh'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. Given the prevalence of Scots pine in the Scottish rural landscape, the disease is spread throughout the country. While there are no reported cases of red band needle blight on urban trees, 4.5% of Edinburgh'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 Southern Scotland. The great spruce bark beetle poses a threat to 0.8% of Edinburgh's urban forest.

Glossary of Terms

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

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

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

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

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

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

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

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

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

Meteorological - phenomena of the atmosphere or weather

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

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

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

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

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

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

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

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

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

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

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.