Valuing Derby's Urban Trees

The Research Agency of the Forestry Commission

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.

A project for: **Derby City Council (Derby CC)**

Citation

This report should be cited as:
Sales, K., Chambers-Ostler, A., Walker, H., Handley, P., Sparrow, K., Hill, D., and Doick, K.J. (2022). Valuing Derby's Urban Trees; A report to Derby City Council. Forest Research, Farnham. 123 pp.

Copies of this report, its two-page summary, and one-page infographic can be downloaded from:

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

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Key Definitions

Urban forest: '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' (Davies et al. 2017).

i-Tree Eco: a software application which quantifies the structure and environmental effects of urban trees and calculates their value to society. It was developed as the urban forest effects (UFORE) model in the 1990's to assess impacts of trees on air quality and has since become the most complete tool available for analysing the urban forest. Eco is widely used to discover, manage, inform decisions on, and develop strategies concerning trees in urban landscapes – www.itreetools.org.

Natural capital: refers to the elements of the natural environment, such as the trees of an urban forest, that provide goods, benefits, and services to people, such as clean air, food, and opportunities for recreation (Natural Capital Committee 2014). As the benefits provided by natural capital are often not marketable, they are generally undervalued, and inventories limited. This can lead to poor decision making about the management and maintenance of natural capital.

A full Glossary is provided in Appendix V.

Executive Summary

Urban trees form a resource that provides a range of benefits to human populations living in and around cities. Termed ecosystem services, the benefits provided by urban trees help to offset many of the problems associated with increased urban development. Trees remove certain air pollutants, capture and store carbon, reduce water runoff and flooding, and influence urban microclimates through cooling. They provide habitats for other species of plant and animal, a space for people to relax and exercise, and they can improve social cohesion in communities. These benefits, however, are directly influenced by the management actions that dictate the structure, composition, and health of the urban forest resource.

To gain a better understanding of the structure and service provision of Derby's urban forest we utilised the widely used tool for assessing and evaluating urban forests, **i-Tree Eco v6.0**. The information provided by this tool enables decision makers to understand threats, set goals and monitor progress towards optimising Derby's urban forest resource. i-Tree Eco also assigns monetary values to some services such as carbon storage and pollution removal, thus increasing the profile of Derby's urban forest, and thereby help to ensure its value is maintained and improved upon.

The data presented in this report provides detailed information on the structure of Derby's urban forest, its **composition, condition, and public amenity value**. It demonstrates that residents of, and visitors to, Derby benefit significantly from urban trees. In terms of avoided water runoff, carbon sequestration and the removal of three types of air pollutants, Derby's urban forest **provides ecosystem services worth £3.3 million per year**. Though this value is high, it is an **underestimate** as it excludes many ecosystem services that i-Tree Eco cannot currently assess, including cooling local air temperatures and reducing noise pollution. This study captures a snapshot-in-time. It does not consider how the urban forest has or might change in future, or the reasons for this change. However, it does provide a means to make informed decisions on how the structure and composition of Derby's urban forest should change in the future, and how to ensure that it is resilient to the effects of a changing climate.

The study was commissioned by Derby City Council (Derby CC), and delivered by Forest Research and Treeconomics.

Headline Facts and Figures

Structure and composition of Derby's urban forest in 2021		Page
Estimated total number of trees	255,000	27
Estimated average tree density (trees per ha)	33	27
Estimate of total tree canopy cover (%)	8[1]	28
Number of tree species surveyed Number of tree genera surveyed	61[2] 80[3] 42	30
Top three most common species surveyed	Leyland cypress, Sycamore, Silver birch	30
Land uses where a greater percentage of surveyed trees were found	Residential, Park, Institutional	34
Percentage of surveyed trees of different sizes (by DBH)	7-20 cm, 44.3%; 20-40 cm, 35.5%; 40-60 cm, 10.7%; >60 cm, 9.4%	37
Percentage of trees in good or excellent condition	87%	40
Ward with the most tree cover Ward with the least tree cover	Allestree Chaddesden	69

Estimated ecosystem service provision amount and value in 2021			
Annual avoided water runoff	81,090 m^3	£79,728	45
Annual pollution removal	60 tonnes	£278,200	48
Annual net carbon sequestration	3,233 tonnes	£2,903,234	52
Carbon storage	106,825 tonnes	£95.9 million	52
Replacement cost	CAVAT amenity value of all trees: £1,020 million Structural value[4] of all trees: £244 million		59
Total annual benefit[5], and Benefit:Cost ratio	Total per annum benefit to Derby society: £3,261,162. Management and maintenance budget for Derby's public trees: £512,900. Benefit: cost ratio of Derby's public urban forest s to costs is 2.3:1.		

1. From i-Tree Eco, 2. Identified species, 3. Unique entries which includes unknown species, 4. Also termed replacement value. 5. Sum of 'flow' services: pollution, carbon sequestration, and runoff.

How can this report be used?

This report provides baseline information on the structure, composition, and benefits delivery of Derby's dynamic urban forest. By raising awareness of the value of benefits provided by Derby's trees, the report can be used to promote, optimise, and equalise investment in green infrastructure across and within sections of the city.

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

- Maintaining, or improving, current tree cover.
- Identifying areas that would benefit from enhanced protection, for example from development.
- Identifying locations which would directly benefit from green infrastructure.
- Optimizing existing, and new, green infrastructure.
- Offsetting known forecasts of loss of tree cover through development or pests and diseases.

This report can also be used by:

- Those writing policy.
- Those involved in strategic planning to build resilience or designing the sustainable development and resilience of the city.
- Those who are interested in local trees for improving the health, wellbeing and enjoyment of themselves and others within the city.
- Those keen to conserve urban nature.

Key Conclusions

- The species richness, diversity, and size class distribution of Derby's urban forest is better than the average of several other UK urban surveys. There is an **over-abundance of Leyland cypress.** Further, the **canopy cover and health condition of Derby's trees is comparatively poor**. Further investigation into the species and locations with poor health would be beneficial.
- Large trees are well represented in Derby compared to other UK i-Tree Eco studies. However, **certain land uses (e.g. Commercial / Industrial) and regions (e.g. Central)** should be managed to **bolster the number of mature,** large-stature trees, given that large sized trees provide proportionally more ecosystem services than small stature trees.
- Of the trees recorded, an estimated **69% were growing within private land** uses. An important resource for the city that is outside of its direct control and therefore potentially vulnerable to change not directed by a management strategy. Increasing **public awareness** of the significance of this resource, and how to maintain and enhance it, through an education and engagement programme could be an important goal going forward.
- Pest and disease risk management should be considered as a priority for future management plans for Derby's urban forest. **Chalara and Ramorum disease** are the highest risk diseases considering their presence in the Midlands. However, the relative abundance and value of ash in, and therefore the potential cost of Chalara to, Derby's urban forest is lower than other UK studies. Of the potential pests considered, **Asian longhorn beetle** if established in the UK, would be the most damaging to Derby's forest. Resources from groups like Forest Research and the Royal Horticultural Society provide **guidance on reducing the risk of disease and climate change stress** through monitoring and tree species selection.

Introduction

The urban forest comprises all the trees in the urban realm, in public and private spaces, along linear routes and waterways and in amenity areas. It contributes to green infrastructure and the wider urban ecosystem (Doick et al. 2016). Urban forests are an essential component of urban ecosystems, as they provide a broad variety of important benefits to society. These benefits, widely termed ecosystem services, support the physical and mental health of residents, make urban areas more enjoyable and healthier places to live, and reduce risks from flooding, climate change, air pollution, and high urban temperatures (National Ecosystem Assessment 2014). If the ecosystem services provided by urban trees did not exist, urban areas would require unprecedented levels of investment in engineered solutions to obtain the same results.

This report presents the findings of an i-Tree Eco survey and urban forest assessment, undertaken in Derby in 2021. **The report aims to provide a 'baseline' understanding of Derby's urban forest**, incorporating elements such as forest structure, species distribution and diversity, and then quantifying some of the ecosystem services that Derby's trees provide. i-Tree Eco projects can improve our understanding of urban forests beyond just using canopy assessments and, when used in conjunction, both may help to shed light on the causes of identified trends or emphasise reasons behind low tree quantity, quality, or both.

i-Tree Eco was developed by the USA i-Tree Cooperative, an initiative involving USDA Forest Service, Davey, Arbor Day Foundation, the Society of Municipal Arborists, International Society of Arboriculture and Casey Trees, which aims to assess the make-up of urban forests and estimate its value. the Cooperative is i-Tree Eco has been assessed as a fit-for-purpose tool for valuing UK green infrastructure (Ozdemiroglu et al. 2013), and has been utilised successfully in over 40 areas in the UK, and in hundreds of cities globally.

Derby is the 18th most populous major settlement in Britain (Office for National Statistics 2021), with estimates of population size including 256,814 and 264,430 in 2020 (Derby City Council 2021e; Office for National Statistics 2021). It is projected that by 2045 its population will exceed 274,000 (Derbyshire County Council 2021). The expansion and infilling of urban areas for residences to accommodate this growing population, can put pressure on the urban forest by reducing the number and size of trees able to be planted. Further losses are predicted to arise from infrastructural developments like the A38 expansion

(Highways England 2020). The risk of future losses to Derby's urban forests may be concerning, considering the trend of reducing urban tree cover in Derby over the past two decades (World Resources Institute 2021). However, there is growing support for expanding and improving urban green infrastructure. Locally, Derby CC has approved a pioneering UK project of rewilding a large urban green space; Allestree Park (Derby City Council 2021a). At the UK-scale, multiple targets, action plans, and funding opportunities have recently been announced, such as net zero emissions by 2050, and halting the decline of biodiversity by 2030 (DEFRA 2021). Approximately £500 million of the £640 million Nature for Climate Fund is dedicated to trees, with the aim of planting 30,000 hectares per year, and a woodland cover target of at least 12% by 2050. Furthermore, £6 million has been allocated to the Urban Tree Challenge Fund (DEFRA 2021), with an objective of planting of 44,000 large 'standard' trees over two years (Forestry Commission 2019).

In the next section, we introduce the concept of ecosystem service provision, as required to understand the i-Tree approach to urban forest assessment. This material facilitates city councils to make informed plans to achieve their green infrastructure objectives. Moreover, it helps focus investment on the urban forest through managed intervention to maximise benefit, and avoid (potentially costly) loss, through protection and development.

Ecosystem Service Provision

The National Ecosystem Assessment (2014) and the Millennium Ecosystem Assessment Board (2005) outline frameworks to examine the possible goods and services that ecosystems can deliver, according to four categories: regulating, supporting, provisioning, and cultural services. Tables 1 and 2, as well as Figure 1, present the significance of range of ecosystem services provided by Derby's urban forest.

For a more detailed review of ecosystem service provision by urban trees, and how this varies depending on the environment, tree structure, composition, and management, see Davies *et al.*, (2017); a Forestry Commission Research Report. Quantifying and assessing the value of the services provided by the natural capital of Derby's urban forest will help raise the profile of urban trees, and can inform decisions that will improve human health and environmental quality.

Table 1. Review of the ecosystem services measured as part of the i-Tree Eco, and their significance to Derby.

Ecosystem service	Role of urban trees	Significance to Derby
Avoided runoff	Tree canopies and root systems intercept rainfall, reducing the volume of water that forms surface runoff which often feeds into rivers. Flooding from intense runoff is a serious risk in urban areas, it increases the costs of sewerage treatment and fluvial defences.	Flooding is predicted to be the greatest climate change risk to the UK (East Midlands Councils 2015), with rainfall expected to increase by 10% by 2100 (Intergovernmental Panel on Climate Change 2014). In England between November 2019 and March 2020 4,300 properties were flooded, with an estimated economic loss £333 million (up to £9.3 billion of damage was prevented by current defences) (Environment Agency 2021). 3,600 properties in Derby, and the surrounding area, have been identified at risk from a '1 in a 100 year' flood from the river Derwent (East Midlands Councils 2015). ~385 properties upstream in Matlock were inundated in 2019 (Black and Ward 2020).
Air pollution removal	Trees intercept air pollutants, reducing exposure of people to pollutants that can be harmful to health.	Air pollution is linked to ca. 36,000 UK deaths annually, and is attributable to 5.1% of mortalities in the East Midlands (Public Health England 2019). In Derby two Air Quality Management Areas (AQMAs) have been declared due to high NO_2 levels (Suschitzky 2020a). A Air Quality Action Plan has been created to target NO_2 and $PM_{2.5}$ emissions (Suschitzky 2020b).

Carbon storage & sequestration	Trees remove CO_2 from the atmosphere and store carbon in their wood, helping to mitigate global climate change.	Relative to pre-industrial levels, a doubling of the atmospheric CO_2 concentration is likely to lead to a warming of 2ºC and associations with rising sea levels, extreme weather, altered food supplies, habitat loss, and extinctions (Intergovernmental Panel on Climate Change 2014). Derby's carbon footprint was estimated at 2.4 million tonnes CO_2e in 2018 (Derby City Council 2021b), and its per capita CO_2 emissions was 6.0 tonnes in 2011 (Derby City Council 2015). However, Derby is reducing its footprint with green spaces, and has declining CO_2 emissions.
Habitat provision	Urban trees support a range of biodiversity in urban areas, providing opportunities for residents to engage with nature.	Up to 40% of species are predicted to be committed to extinction by 2050 with a mid-intensity climate change projection (Thomas et al. 2004). Derby contains 375 open spaces, which includes the oldest surviving public park (Derby Parks 2021), the largest UK rewilding project (Derby City Council 2021a), and a Site of Special Scientific Interest (Natural England 2021).
Amenity value	The cost of replacing trees accumulated innate value. A tree's value increases with its size, health, accessibility, scope for growth, and location-specific character.	Derby City contains hundreds of trees protected under tree preservation orders (Derby City Council 2021c), and a champion Weymouth Pine (*Pinus strobus*) (Mitchell, Hallet, and White 1990). In a UK public perception of urban forests survey, 40% of 6,000 participants wanted more and larger trees (Ambrose-oji et al. 2021).

Table 2. Review of ecosystem services provided by urban trees that were not measured as part of the project, and their significance to Derby.

Ecosystem service	Role of urban trees	Significance to Derby
Cultural value	Trees improve social cohesion by providing spaces to meet. Trees help to create a sense of place and old trees help create a link to local history and nature.	Over the past 5 years in the UK the number of people within 4 km of a 20 ha, or larger, woodland has reduced by 73% (Reid et al. 2021). Urban trees and green spaces are being increasingly recognised as influential for wellbeing. In a recent survey, 50% of respondents felt more connected to urban trees since COVID lockdowns, and 54% were annoyed by urban tree damage/loss (Ambrose-oji et al. 2021).
Noise reduction	Trees can act as a barrier to noise and reduce stress levels from heavy traffic.	Traffic was ranked 6th most common in 21 options for explanations of lowering Derby resident satisfaction (BMG Research 2017). Noise reduction is publicly recognised as a benefit from urban trees (Ambrose-oji et al. 2021).
Educational value	Trees and woodlands create learning opportunities for children. Adults' involvement and training in tree management can also develop new skills.	Over five surveys spanning a decade in England, 78% of respondents thought woodlands were important for learning (Ward and Stag 2021). Trees are important resources for engaging and learning for example, the Woodland Trust's awards, community projects and events has reached 70% of UK (Reid et al. 2021).
Temperature regulation	Urban temperatures are often higher than rural areas. Tree canopies provide shade and water	In 2008 heat-related stress accounted for 1,100 premature UK deaths annually (NHS/Department of Health 2008). Moreover, the 2003 European heatwave, where London's Urban Heat

	transpiration, reducing local temperatures and the need for air conditioning. This improves people's comfort and reduces CO_2 emissions.	Island (UHI) was 9°C (Greater London Authority 2006), was attributed to 70,000 premature deaths. In 2018 homes in Derbyshire lost access to water due to excessive demand (UK Parliment 2018). A review of 75 articles found that vegetation cover was 'crucial' for reducing surface temperatures by up to 24°C (Deilami, Kamruzzaman, and Liu 2018). In London and Bristol green spaces have mitigated the UHI effect (Smith et al. 2011; Vaz Monteiro et al. 2016).
Landscape enhancement	Urban trees can improve the image of places and how people enjoy them, raise property values, and increase footfall in commercial areas. Trees can have a restorative effect, improving mental well-being.	More deprived areas tend to have less tree cover (Reid et al. 2021). Aesthetics, especially seasonal variation, is publicly recognised as a benefit from urban trees (Ambrose-oji et al. 2021). In a Derby residents survey maintenance of green infrastructure came 6^{th}/15, 9^{th}/21 and joint 13^{th}/16 as a reason for dissatisfaction, worsening approval and satisfaction respectively (BMG Research 2017)
Recreation	People are more likely to engage in physical activity in greener environments, improving resident's physical and mental health (Kondo et al. 2018).	Nationally Derby is ranked in the middle 50% for 13 of 27 sport/activity metrics, and in the bottom 25% for the rest (Derby City Council 2008). Recreation, especially for children, is publicly recognised as a benefit from urban trees (Ambrose-oji et al. 2021). Over five surveys spanning a decade in England, 86% of respondents thought woodlands were important for exercise (Ward and Stag 2021).

Figure 1. Visual examples of tree ecosytem services. Clockwise from top left: 1) linear features of trees can reduce noise and atmospheric pollution; 2) a variety of colour and shape enhances the visual appeal of landscapes, as shown above by silver birches and cypresses; 3) trees are some of the richest habitats, providing structural space and food, such as rowan berries; and 4) trees, like the limes here, stabilise the local climate through casting shade and evapotranspirative cooling.

The distinction between Table 1 and 2 highlights that currently only a subset of the ecosystem services provided by urban trees are able to be quantified and valued by i-Tree Eco. **The value of Derby's urban forest presented in this report should therefore be recognised as a conservative estimate** of the value of the full range of benefits that this urban forest provides to the residents of, and visitors to Derby.

Further caveats to an i-Tree Eco valuation include:

- The v6 i-Tree Eco model provides a snapshot-in-time picture of the size, composition, and condition of an urban forest. To be able to assess changes in the urban forest over time, repeated i-Tree Eco studies, or comparable data collection, would be necessary.
- i-Tree Eco demonstrates which tree species and size class(es) are currently responsible for delivering which ecosystem services. Such information does not necessarily imply that these tree species should be used in the future.
- 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 report on these factors itself.
- 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.
- Planting and management must not rely solely on i-Tree Eco results, but also be informed by:
    - Site-specific conditions, such as soil properties, and available growing space
    - the aims and objectives of the planting or management scheme
    - local, regional and/or national policy objectives
    - current climate and future climate projections and associated threats; and
    - guidelines on species composition and size class distribution for a healthy resilient urban forest.

For further guidance, refer to the Urban Tree Manual (Defra, 2018).

Opportunities and Limitations

The information in this report supports decision makers in their efforts to achieve:

Economic objectives

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

Environmental objectives

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

Social objectives

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

What difference can i-Tree Eco make?

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

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

Further Information

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

For further details on i-Tree Eco in the UK, on-going i-Tree Eco model developments, training workshops, or to download reports on previous UK i-Tree Eco studies visit www.forestresearch.gov.uk/research/i-Tree-eco or https://www.treeconomics.co.uk/resources/reports/.

The identification, measurement, mapping and caring of trees in the urban environment create opportunities for members of the general public and community groups to become 'citizen scientists'. Interested readers are referred to Treezilla: the Monster Map of Trees (www.treezilla.org) and the Canopy Cover web page on Forest Research's website (https://www.forestresearch.gov.uk/research/i-Tree-eco/urbancanopycover/).

Methodology

Survey Area and Sampling Design

i-Tree Eco uses a plot-based method of sampling, from which the recorded data is extrapolated to statistically represent the whole study area. For this study, 366 plots were randomly distributed across the City of Derby. Plots were stratified (shared) across the city to represent its 17 electoral wards (Appendix IV: Table A3). Furthermore, wards were grouped into four geographic regions. The boundaries adopted for the study, and the location of the plots are presented in Figure 2. Of the allocated 366 plots, 360 were completed.

The study encompassed 7,801 ha leading to one sample plot every 22 ha. This sample density is higher than most previous studies (for example, Table 5).

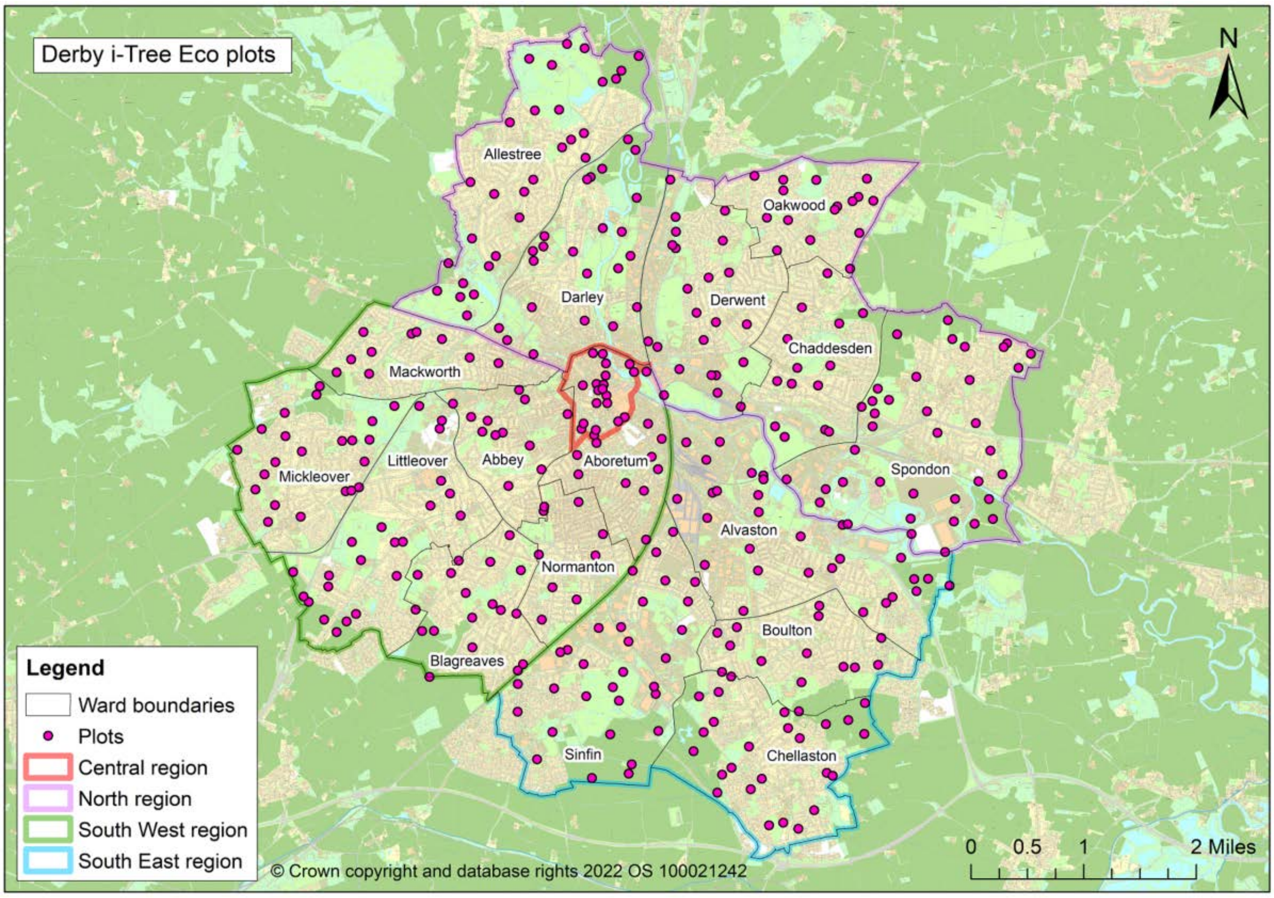

Figure 2. The Derby study area. Study area regions, and electoral wards are highlighted. Plots were stratified so that a certain number adequately represented each region. Plot co-ordinates were randomised within this.

i-Tree Eco data collection

Within each of the 360 plots a series of measurements were taken including land use and vegetation cover at the plot level, as well as tree and shrub biometrics within it. Unlike previous versions of Eco, v6 contains the required climate, weather, phenology, and air pollution data, so these were not collated for modelling (i-Tree 2021). A summary of calculations is presented below. However, spatio-temporally relevant economic data still needed manual collection. Lists are provided for field data outputs (Table 3) and the subsequent calculations (Table 4).

Plot data collection in the field

i-Tree Eco uses a standardised field collection method outlined in the i-Tree Eco Manual v6 (i-Tree 2021) and this was applied to each plot. Each plot covered 0.04 ha (circle with radius 11.3 m) and from each was recorded the following data collected:

- Within each plot, the percentage of ground in the circle which contains:
  - Each type of land use, e.g., park, residential, institutional.
  - Each type of the ground cover e.g., grass, concrete, water.
  - Which is covered by tree canopy.
  - Which contains shrub cover.
  - Which currently does not have trees, but would be amenable to hosting them (plantable space).
- Information about trees including:
  - Number of trees and their species.
  - Size of the trees including height, canopy spread and diameter at breast height (DBH) of trunk measured at 1.5 m above ground level.
  - Whether it was a street tree or if it was in public land (public land included parks, streets, and cemeteries).
  - Condition of the trees including the fullness of the canopy and the percentage of dieback.
  - Amount of light exposure the canopy receives.
  - Amount of impermeable surface (e.g., tarmac) under the tree.
- Information about shrub areas including:
  - The dimensions.
  - The relative amount of each species.

Table 3. Outputs calculated based on field collected data.

Outputs	Collected field data inputs[1]
Urban forest structure and composition	Species diversity, canopy cover, age class, condition, importance, and leaf area. Urban ground cover types. % leaf area by species.
Annual ecosystem services	Air pollution removal by urban trees for CO, NO_2, SO_2, O_3, $PM_{2.5}$ and a value in £ based on *the UK damage costs for the removal of* NO_2*,* $PM_{2.5}$ *and* SO_2 *or* the USA externality cost prices (USEC) for CO and O_3 where UK costs are not available. Annual carbon sequestered and value in £, values of per metric tonne of CO_2 (UK's Buisness Engery Inovation's Valuation of Greenhouse Gas Emissions) Rainfall interception from local climate data in i-Tree Eco, and avoided volumetric sewerage charges value in £ from the main local water company.
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 £, values of per metric tonne of CO_2 (UK's Buisness Engery Inovation's Valuation of Greenhouse Gas Emissions)
Habitat provision	*Foliage invertebrates, pollen and nectar provision, fruit and seed provision.*
Potential insect and disease impacts	*Chalara dieback of ash, acute oak decline, Asian longhorn beetle, two lined chestnut borer, bronze birch borer, emerald ash borer, alder bleeding canker, oak processionary moth, Phytophthora alni, Ramorum disease, bacterial leaf scorch.*

1. Italics highlight non-standard i-Tree outputs gathered by the authors.

Replacement Cost and Amenity Value

i-Tree Eco provides replacement costs for trees based on the valuation method used by the Council of Tree and Landscape Appraisers (1992). In addition to the CTLA method, an amended version of the CAVAT Quick method was included (Doick et al. 2018). CAVAT has been developed in the UK and has previously supported councils' planning decisions. CAVAT gives a value for trees in towns, based on an extrapolated and adjusted replacement cost. This value relates to the replacement cost of amenity trees rather than their worth as property per se (as per the CTLA method). Particular differences to the CTLA trunk formula method include the addition of the Community Tree Index (CTI) factor, which adjusts the CAVAT value to take account of greater amenity in areas of higher population density, using official population figures. The methods for both i-Tree Eco calculations, and additional calculations including CAVAT, are provided in detail in Appendix I.

Pests and Diseases

Pest susceptibility was assessed using data on the number of trees within pathogen/pest target groups and the prevalence of the disease or agent within Derby or the wider UK. A risk matrix, devised by the authors, was created for determining the potential impact of priority pests and diseases, should they become established in the urban tree population of Derby.

Habitat Provision

Trees and shrubs provide valuable structural habitats for animals and epiphytic (attached to plants) moss and lichen (Sales, Gardner, and Kerr 2016). Moreover, trees and shrubs are a huge accumulation of biomass available for consumption by mammals, birds, and insects. Furthermore, such plants support many mutualisms (cooperative interactions) including a plethora of soil microbes. A review of the value of different tree species to UK wildlife by Alexander, Butler and Green, (2006) is used to examine the relative biodiversity value for urban trees, supplemented with information from Southwood (1961), Kennedy & Southwood (1984), and RHS (2018a). Alexander et al. review a wide range of biodiversity values, giving trees a score from 5 (high value) to 0 (low value). Three examples are shown in the report (foliage invertebrate value, nectar and pollen value, and fruit and seed value).

Comparisons to Other UK i-Tree Eco Studies

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

- Cardiff (Hand et al. 2018)
- London (Rogers et al. 2015)
- Edinburgh (Doick, Handley, et al. 2017)
- Wrexham (Rumble et al. 2015)
- Burton-on-Trent (Bentley and Hewgill 2016)

Summary of the Report's Calculations

Table 4. Summary of the report's calculations.

Variable	Calculated from
Number of trees	Total number of estimated trees extrapolated from the sample plots.
Tree canopy cover	Total tree cover extrapolated from estimates within plots.
Identification	Most common species found, based on field observations.
Pollution removal value	Based on UK social damage costs (UKSDC): £6,385 per tonne NO_x (nitrogen oxides, to represent NO_2), £13,026 per tonne SO_2 (sulphur dioxide), and £73,403 per tonne $PM_{2.5}$ (particulate matter) (Birchby et al. 2020).
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 (as estimated by i-Tree Eco using local climate data). The value used was the household standard volumetric rate of public sewerage charges set by Severn Trent Water (£0.98 per m^3) in 2021/22 (Severn Trent Water 2021).
Carbon storage & sequestration values	The baseline year of 2020 and the respective values of £245 and £898 per metric tonne of CO_2 and Carbon (DBEIS 2021)
Replacement cost (direct replacement)	The value of the trees based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree), the value is determined within i-Tree Eco according to the CTLA (Council of Tree and Landscape Appraisers) v9 method.
Replacement cost (amenity valuation)	Using the Capital Asset Value for Amenity Trees (CAVAT) Adjusted Quick method.

Results and Discussion

Table 5. Outputs from Derby's i-Tree Eco survey compared to five examples across the range of previous UK surveys.

	Derby	Cardiff	London	Edinburgh	Wrexham	Burton-on-Trent
Study area size (ha)	7,801	14,064	159,064	11,468	3,833	2,851
Number of trees ('000's)	255[1]	1,410	8,421	712	364	103
Plot density (ha per plot)	22[2]	71	221	57	19	12
Canopy cover (ha)	645	2,658	22,326	1,950	652	257
% Tree canopy cover	8.1[3]	19[3]	14[3]	17[3]	17[3]	9[3]
Number of trees per ha	33	100	53	62	95	36

Table 5 highlights that Derby is a moderately sized study area, with a moderately high sampling density (one plot every 22 ha). It contains a relatively low canopy cover and tree density.

1. Extrapolated from 457 trees in sample area.
2. Based on 360 plots were sampled from the initial 366.
3. Based on calculation from i-Tree Eco sample.

Canopy Cover

The tree canopy cover of Derby reported by i-Tree Eco surveying was 8%. When comparing like-with-like Derby's canopy cover is low relative to: Cardiff, (19%); London (14%); Edinburgh (15%), or Wrexham (17%).

When calculating the tree canopy cover using i-Tree Canopy, linked to the **canopy cover web map** (Urban Forest Research Group 2022)**, the average across the 17 urban wards of Derby was 15.0%[1].** This mean value is slightly higher than the 13.3% mean of the nine rural wards adjacent to Derby. Derby's canopy is comparable to the 14.7% value of urban areas of the East Midlands. However, Derby's is less than the averages of 17.5% and 17.0% for urban England and UK, respectively. When urban localities across the UK are ranked in descending order on the UK canopy cover webmap[2] Derby achieves 216th out of 341. This rank is tied with six other areas, including Glasgow City (Urban Forest Research Group 2022).

Ground Cover

Ground cover in Derby consisted of 53% permeable materials, such as grass and soil; the remainder was of non-permeable surfaces such as tar (asphalt), concrete and cement. Impermeable surfaces contribute to the Urban Heat Island effect and slow precipitation infiltration to soil, which increases the risk of flash flooding, and drought stress on trees. The percentage of permeable cover in Derby is towards the low end of previous i-Tree Eco surveys, for example: Wrexham (52%), Edinburgh (55%), Cardiff (59%), and London (60%).

Land use

The three most common land uses in the sample plots were residential (38%), commercial/industrial (15%), then parkland (11%) (Figure 3). Additionally, **the three most abundant land uses which contained trees were residential (55%), parkland (16%), followed by institutional (8%)**. Consequently, the majority of plots, and plots with trees, were encompassed by the top two land uses in each category.

1. Canopy cover averages from the webmap are averages of ward-level values weighted by the surface area of each ward.
2. Data extracted from the UK urban canopy cover webmap in December 2021 (Urban Forest Research Group 2022).

The average canopy cover of residential, park, and commercial/industrial land was 6%, 17%, and 3% respectively. Although only accounting for 1% of land, golf-courses had the greatest canopy cover of 37%. Similarly, the next highest canopy cover, 24% was in water/wetland, which just made up 1% of land use. For the top three land uses, the mean plantable space, permeable ground with an unobstructed space above, was: park, 34%; residential, 11%; commercial, 4%. Despite being just 8% of land use, agricultural land had the greatest plantable space of 46%.

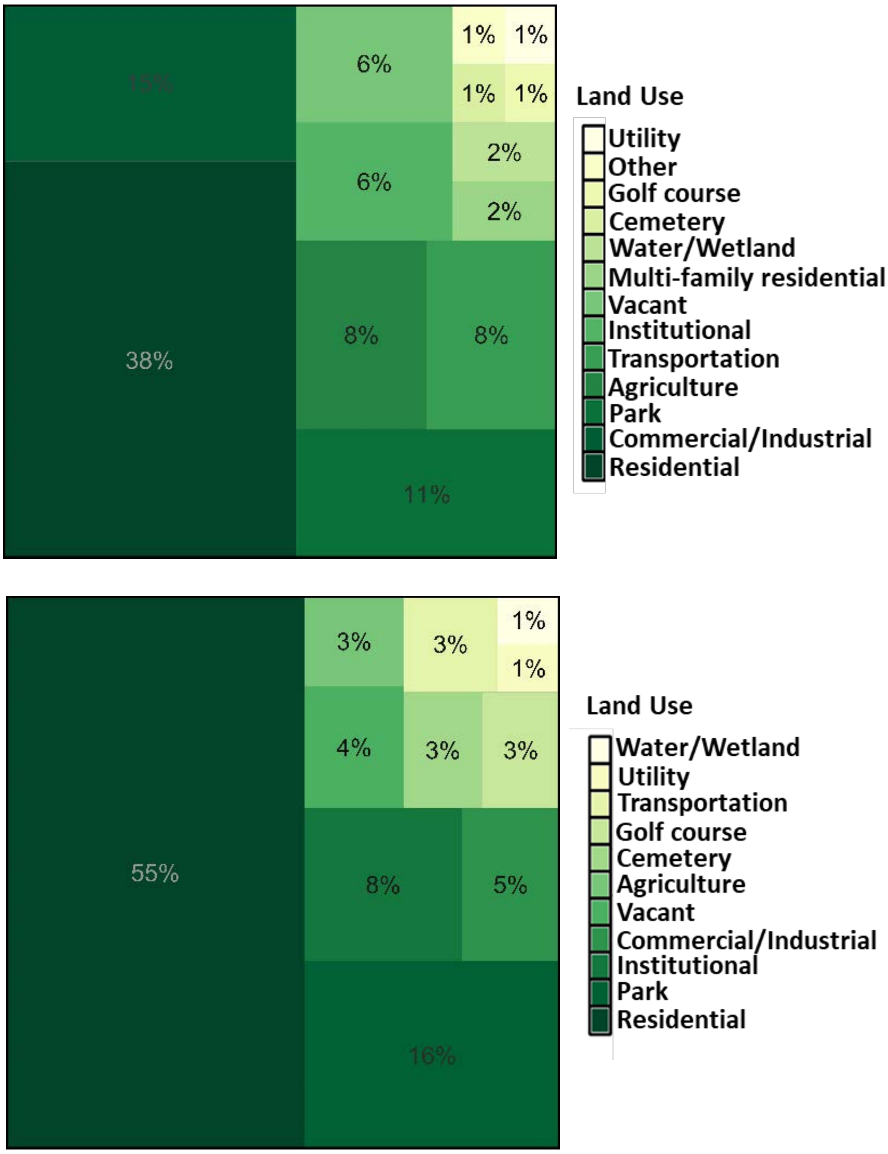

Figure 3. Percentage of plots falling into each of the different land uses, for both all plots (top) and only for the subset of plots which contained trees (bottom). Plots could contain more than one land use, for example, stranding the boundary between a private residence and school. Each plot was defined by the dominant function in each plot. For a definition of land uses see Appendix I: Table A1.

Urban Forest Structure

Species Composition

Richness and Diversity

A total of 61 individually identified tree species and were encountered during the study[1] (for a full list of tree species see Appendix II: Table A2). The total unique entries for species was 80 (including 'spp.' where an identification beyond genus was not possible). Derby's unique entry richness of 80 was higher than previous i-Tree Eco reports for Bridgend (60 species), Cardiff (73 species), and Wrexham (54 species). However, Derby richness was lower than recorded in the Tawe catchment (88 species). The three most abundant species were Leyland cypress (× *Cupressocyparis leylandii* (recently accepted as × *Hesperotropsis leylandii*)), sycamore (*Acer pseudoplatanus*), and silver birch (*Betula pendula*). The three genera with the greatest tree abundance were: maples (*Acer* spp.), 5 species; Leyland cypresses (× *Cupressocyparis* spp.), 1 species; and cherries/plums (*Prunus*), 7 species.

The ten most common tree species accounted for the majority (52%) of the trees surveyed (Figure 4). Santamour (1990) recommended that for urban forests to be resilient to pests and diseases, no species should exceed 10% of the population, no genus surpass 20%, and no family top 30%. One species, Leyland cypress, exceeded the 10% guideline. No genus exceeded a 20% share. The rose (Rosaceae) family was the most well represented, 24% of individuals fell into this group, the cypress (Cupressaceae) (16%), and the maple (Aceraceae) (13%) families were next most abundant. Therefore, the 30% recommendation at the family level was not exceeded.

The diversity index is a measure which considers not only the number of species present, but also the spread, or equitability, of individuals across species. A diverse community is one where species have relatively even abundance, rather than being dominated by a few; a diverse community is likely more resistant to global change, and more efficacious at service provision (Begon, Townsend, and Harper 2006). A common diversity measure is the Shannon-Wiener (H) index, where 1.5 is regarded as low, and 3.5 as high (Rogers et al. 2015).

1. 61 tree species identified at the species level of precision. There were 80 unique entries which also contained general species 'spp.' where the species could not be identified.

The mean H score of Derby's urban forest was 3.3 (Table 6). For UK urban forests this is moderately diverse, being the same as Cardiff, slightly higher than Edinburgh (3.2) and Wrexham (3.1), but lower than London (3.9).

Derby's shrub richness contained 49 species[2] across 59 genera. The three most common shrubs were cherry laurel (*Prunus laurocerasus*), Leyland cypress (*x Cupressocyparis leylandii*), and privet species (*Ligustrum* spp.).

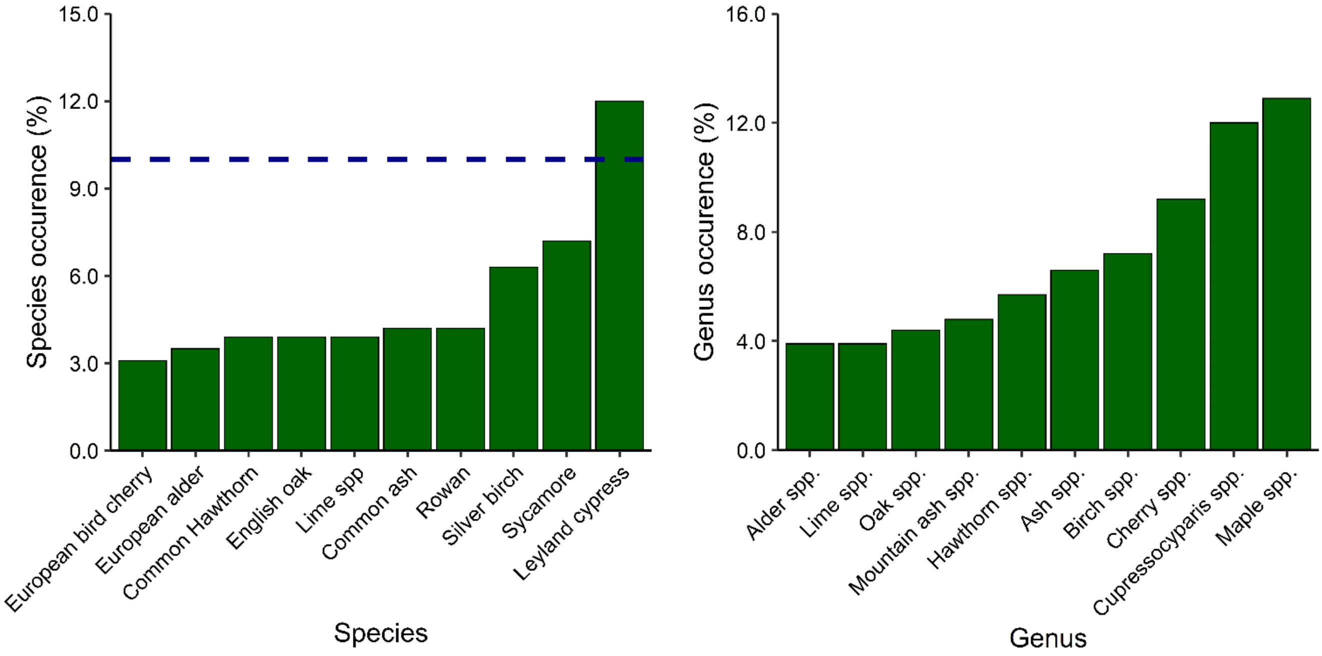

Figure 4. Contribution of the top ten most abundant trees as a percentage of the total tree number, for tree species (left), and for tree genera (right).

2. 49 shrub species identified at the species level of precision. There were 88 unique entries which contained general species 'spp.' where the species could not be identified.

Table 6. Shannon-Wiener diversity index (H) scores for trees on different land use types in Derby.

Land Use	SW Index
Residential	3.0
Park	2.7
Vacant	2.3
Institutional	1.9
Commercial/Industrial	1.8
Agriculture	1.7
Golf course	1.5
Cemetery	1.0
Transportation	1.0
Water/wetland	0.6
Multi-family residential	0
Utility	0
Total	**3.3**

Targeting management for greater diversity

Diversity within the urban forest is a complex issue to tackle; wide variation in environments, land use, and habitat can make overarching strategies successful in some areas, but ineffective and possibly even damaging in others. Identifying specific environments and their individual needs is a key first step in establishing the requirements and actions needed to enhance biodiversity.

With regards to trees, diversity is fairly simple to measure and enhance; it comes down to two metrics, richness and evenness. Richness refers to the number of species identified, however it fails to account for intra-species diversity, i.e. the diversity between trees of the same species. Frequently, amenity trees and cultivars (such as domesticated fruit trees and blossoming cherries) are grown from cuttings and are therefore clones of a parent tree. This makes them more at risk from pests and diseases, as a disease which affects one tree will likely affect them all.

Evenness refers to the spread of a population across the species. A high level of evenness indicates that each species is represented by an approximately even number of trees, while a low level of evenness indicates that a few species dominate the landscape. In cities, evenness is often reduced by a low number of uncommon or non-native species planted in gardens. Using inventories to analyse council-owned trees can give a better view of evenness across a city.

Diversity goes beyond trees, however, as trees act as a host environment to a vast array of creatures. Insects, birds, small mammals, fungi and lichens and other plants rely on trees to provide habitats and food. To improve biodiversity as a whole, it is important to link green areas using ‘green corridors’. These allow for free movement of species across a city and encourage diverse breeding/reproduction to create a resilient population.

Land use and Ownership

Residential, industrial/commercial, and park land were the most common land uses (Table 7). However, they did not necessarily have the most abundant or rich urban forest community. Relative to the total tree count of the study, the most tree-abundant land uses were residential (44%), park (19%), and institutional (11%). Compared to the **total tree richness, the land uses with the largest value were residential (72%), park (33%), and institutional (15%).**

Interestingly, the three most common land uses were dominated by different species, with only sycamore being ubiquitous across the top three (Table 8). The highest diversity of trees was found in residential, park and vacant areas, while water/wetland, multi-family residential and utility had minimal diversity (Table 6). Residential land was also the most diverse in previous studies, like Cardiff, Edinburgh, and Wrexham.

Derby's publicly accessible land (parks, vacant, cemeteries, transport routes), contained 37% of the total tree abundance, and less than half of the total tree richness. The percentage of Derby's urban forest which is in public ownership is relatively low, compared to the estimate that 33% of all trees and shrubs were on public property in a review of English i-Tree Eco surveys (Britt and Johnston 2008). A more recent UK-wide review found variation with between 21% and 75% of trees being on public land, and between 0% and 16% being street trees (Monteiro, Handley, and Doick 2019).

As the majority of Derby's tree abundance and richness is in private ownership, there are greater challenges for the local authority to manage the whole urban forest for tree diversity, health, renewal, pests, and climate adaptation.

Table 7. Tree abundance and richness by the most common land uses for plots which contained trees. Percentages are relative to the total of the whole study.

	Residential	Park	Institutional
Number of trees	197	84	50
Abundance relative to total	44%	19%	11%
Species richness	58	27	9
Richness relative to total	72%	33%	15

Table 8. Contribution of the top five most abundant tree within each land use. Percentages are relative to the total of each land use. The three most common land uses for plot which contained trees are represented.

Residential		Park		Institutional	
Species	%	Species	%	Species	%
Leyland cypress	24%	Common hawthorn	12%	Silver birch	28%
Rowan	6%	Ash spp.	11%	Sycamore	20%
Apple spp.	5%	English oak	8%	Leyland cypress	14%
Sycamore	5%	Sycamore	8%	Lime spp.	10%
European bird cherry	4%	Hawthorn spp.	7%	Common ash	6%

Origin

Of those trees identified to species level in the Derby i-Tree Eco study, it is estimated that 45% are native, and an additional 15% are naturalised, according to the UK tree list in Johnson and More (2006)[2]. Examples of exotic trees within Derby include those native to Asia like the Himalayan paper birch (*Betula utilis*) and red snakebark maple (*Acer capillipes*) as well as those originally from Americas such as the monkey puzzle tree (*Araucaria araucana*) and the southern catalpa (*Catalpa bignonioides*). Interesting varieties/cultivars of native/naturalised trees in Derby include: copper beech (*Fagus sylvatica* 'Purpurea'), Wilson holly (*Ilex x altaclerensis*), crimson king Norway maple (*Acer platanoides* 'Crimson King'), columnar English oak (*Quercus robur* 'Fastigiata'), fastigiate hornbeam (*Carpinus betulus* 'Fastigiata'), and Lombardy poplar (*Populus nigra* v. italica). Derby has a relatively low percentage of trees which are native considering previous studies, such as Edinburgh (53%), Cardiff (56%), Wrexham (59%), but not London (39%).

1. Genus 'spp.' stands for one or more species within the genus.
2. The source material to generate the native list differs slightly from previous studies.

The origin of tree species should be considered, as there are differences in general performance, dimensions, growth speed as well as disease and climate stress tolerance (Murphy et al. 2009). Exotic tees are likely to resist diseases because of enemy release; they have fewer pests and disease associated with them in novel areas as their home range interactions are unlikely to be present, and evolutionary time is required for the adaptation of local organisms to recognise and exploit the exotic host (Connor et al. 1980; Mitchell and Power 2003). Also, trees from warmer climates may be better adapted to the temperature and drought predicted with climate change (Buras and Menzel 2019; Royal Horticultural Society 2021). Conversely, across the globe there are ample examples of exotic trees species becoming invasive (for example Jumbay trees, Rhododendrons, and Lodgepole pines), with repercussions on native species such as elevated competition intensity for resources like light, and shifts towards unfavourable environmental conditions like soil chemistry and fire regime (Begon, Townsend, and Harper 2006; Kew Royal Botanic Gardens 2017; Rundel, Dickie, and Richardson 2014). They can alter species interactions like drawing away pollinator attention. In the same manner that exotic trees are likely to resilient to pests through a lack of recognition, they are also likely to support fewer beneficial species (Kennedy and Southwood 1984).

Size Class Distribution

The size distribution of trees is important for a resilient population. Large trees or mature trees tend to provide relatively more ecosystem services for their costs, when compared to small or immature ones (Hand, Doick, and Moss 2019). Therefore, planting more large stature trees, and supporting more trees to reach maturity, improves ecosystem service delivery. Similarly, ensuring sufficient small trees are present will facilitate recruitment of larger trees and a sustainable urban forest long term. Richards (1983) recommended that the distribution of street trees across trunk diameter at breast height (DBH) classes should be: 40%, <20 cm, 30%, 20-40 cm; 20%, 40-60 cm; and 10%, >60cm.

It is estimated that trees with a DBH of 60 cm made up 9% of the tree population (Figure 5), which is close to the 10% guide. Therefore, Derby performs well in comparison to other i-Tree Eco studies (Edinburgh, Cardiff, London, Wrexham, and Burton-on-Trent) which reported 7% or fewer trees were >60 cm. **However, trees between 40-60 cm DBH contributed to around 11% of the total community; only just over half of the 20% recommendation.** Conversely, the representation of smaller size classes meets the guidelines. The dearth of trees in the second largest DBH class suggests some inefficiency and vulnerability in the short term however, longer term recruitment of smaller classes could be facilitated. The pattern of skew towards smaller size classes is paralleled both within small and large stature trees.

The distribution of tree sizes varies across the different land uses of Derby (Figure 6). Parkland then agriculture conforms most accurately to the 40-30-20-10% guide. From the smallest size class to the largest, parkland's splits are 36-32-18-14%. Agriculture's splits are 44-33-11-11%. Impressively, approximately a third of trees in golf courses and cemeteries are greater than 60 cm. Multi-family residential areas have a bimodal distribution of trees in the largest or smallest classes. Transportation, utility, and water/wetland have no representation in the largest size class moreover, wetland consists entirely of the smallest class.

1. Stature categorisation is based on the maximum reported height of a species, where large trees exceed 12 m.

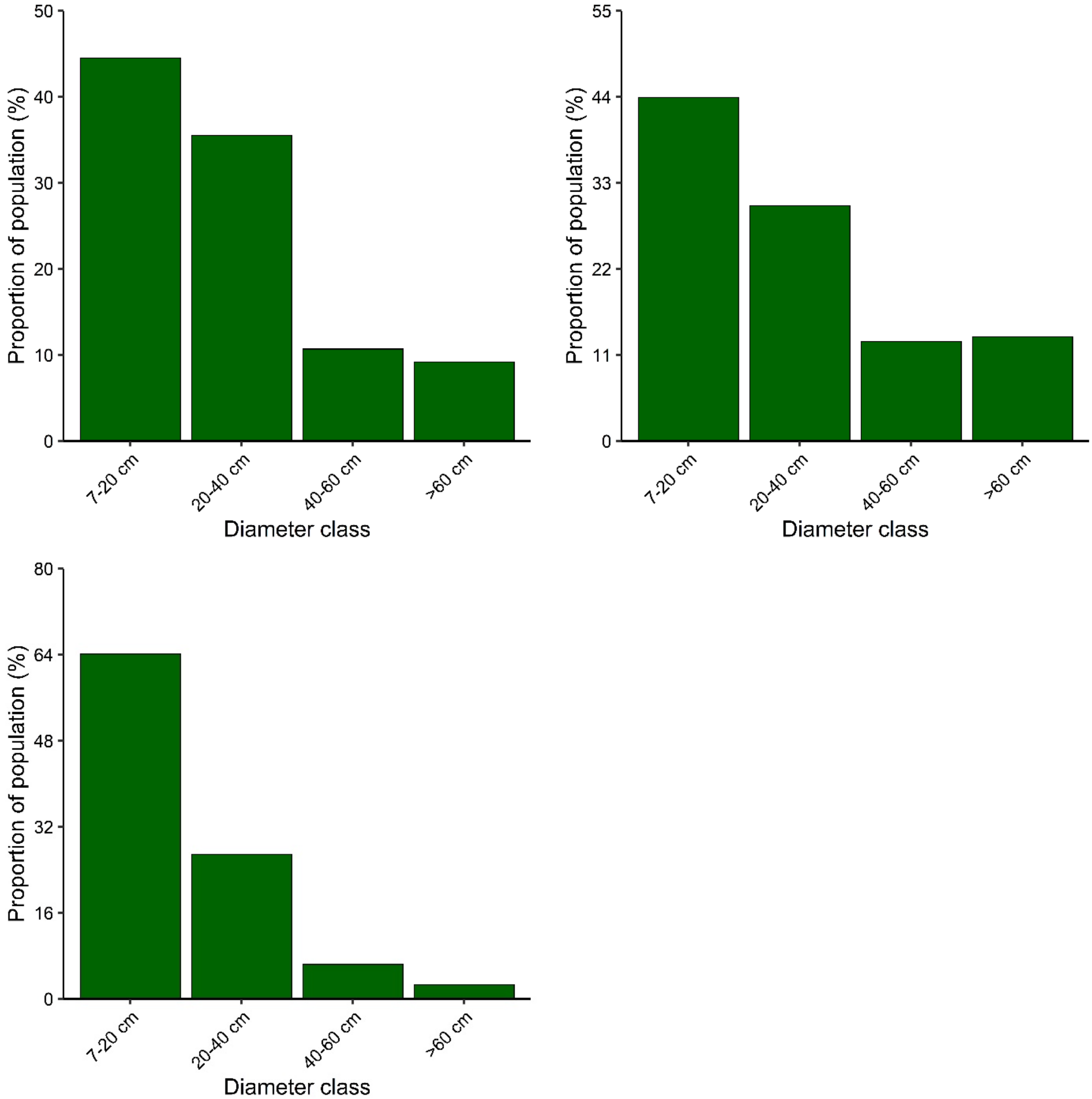

Figure 5. The percentage of the tree population per tree size class, defined by DBH ranges, for all measured trees (top left), large stature trees only (top right), and small stature trees only (bottom left). Stature categorisation is based on the maximum reported height of a species, where large trees exceed 12 m.

Size matters

The size of trees directly impacts their capacity to provide ecosystem services, and therefore is one of the most important aspects of the urban forest to understand within a city. Encouraging the planting of trees which can achieve a large structure, large canopy cover and leaf area and long life can maximise ES provision and amenity value. It is vital, however, to maintain a high level of age and size diversity within a given population, and an ageing population can indicate that not enough planting has been undertaken to support the natural decline of older trees, leading to a net-loss in canopy cover. In a city, it is often perceived that bigger trees come with bigger needs and management requirements, and are therefore more expensive to maintain than smaller trees. However, age plays a large part in dictating a trees management requirements, meaning a smaller, older tree can require more management than a larger, younger tree. Planning and development should account for the space required by large mature trees at the earliest stage of planning to minimise the impact of a growing tree on infrastructure such as pavements, drains and other underground services.

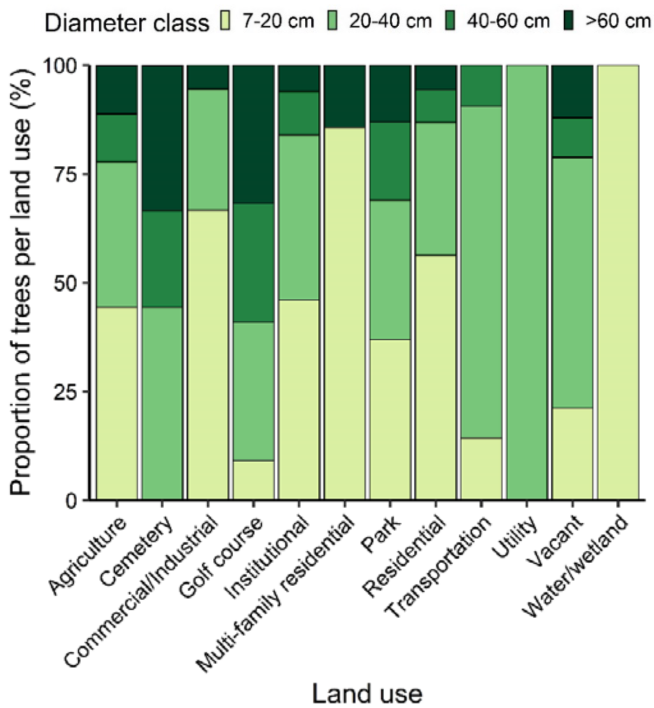

Figure 6. Percentage of DBH size classes per land use type. Land uses were defined by the dominant function in each plot.

Tree Condition

The crown condition scores used to give a broad picture of tree health within i-Tree Eco are related to leaf loss and branch dieback in the crown (i-Tree 2021). Tree health is negatively associated with ecosystem service delivery, for example the carbon storage in street trees (Smith, Dearborn, and Hutyra 2019). Health also signals the likelihood of disease, environmental stress, and/or poor management. However, if not infected with a transmissible and destructive pathogen, the retention of dead trees is important for biodiversity providing a food source for certain feeding guilds and structural habitat (Seibold et al. 2015).

Altogether, Derby's crown condition was:

- Excellent: 16%
- Good: 53%
- Fair: 22%
- Poor: 6%
- Critical: 1%
- Dying: 0%
- Dead: 1%.

Thus, 8% of Derby's trees are estimated as being in the poor, or worse, condition. Derby's trees tend to be less healthy than previous i-Tree Eco studies. For example, 49% of trees in Cardiff were in excellent while 13% were poor-to-dead, similarly Wrexham contained 58% trees in excellent condition and 13% in poor-at-best.

Of the 12 land uses, nine had trees in excellent condition, while three contained dead trees (Figure 7). Institutional, parkland, residential, and transportation land had relatively more trees in the lower classes of crown conditions.

The most abundant crown condition across the ten most common species was good (Figure 7), however, there were inter-species differences in the crown condition spread. **English oaks (33%), followed by sycamore (24%), then Leyland cypress (15%), had the largest percentage of trees in the excellent crown condition category**. Sycamores had the greatest variability in health because, despite the abundance of excellent crowns, 15% of individuals were in the poor, or worse, category. Nonetheless, common hawthorn and silver birch were the only species to contain dead individuals.

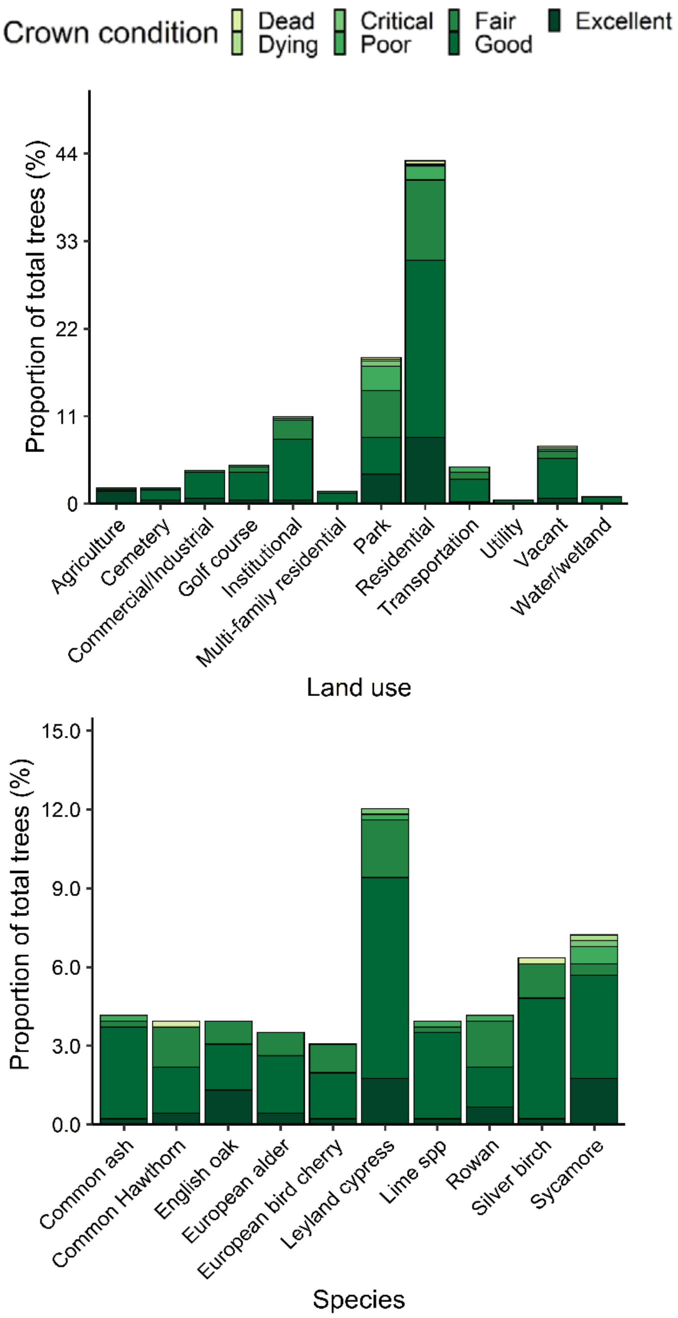

Figure 7. Percentage of trees falling in each crown condition class, by land use (top) and by species (bottom). Land uses were defined by the dominant function in each plot. Crown conditions: excellent, >99% health; good, 99-90% health; fair, 89-75% health; poor, 74-50% health; critical, 49-25% health; dying, 24-1% health; dead, 0% health. Adapted from Nowak *et al.*, (2008). For full definition see Appendix I.

The importance of condition

Tree condition is a crucial metric to monitor when considering the urban forest. It is a key aspect of tree risk management, and can also impact the amenity value of the forest. Tree condition can also be an indicator of pests and diseases, which can be deadly and spread rapidly if not identified. Signs of stress can include dieback, dropping branches, fungal infections, and sprouts/suckers growing at the base of the tree. Identifying stressed trees, the causes of stress, and the correct methods to rectify the conditions can help a tree to recover, fight infection and live longer. Maintenance should include routine inspections of trees, particularly those in close proximity to 'high traffic' areas such as roads, pavements, parks etc. This way, issues can be spotted early and corrected quickly and cleanly to avoid incidents. All tree owners have a duty of care to people and property which may be affected by roots or branches; councils have additional responsibilities with regards to keeping highways and public areas accessible and clear of obstructions, and to keep the public safe.

Leaf Area and 'Importance Value'

The healthy leaf surface area of trees indicates the extent to which trees can provide their benefits, such as the removal of pollutants from the atmosphere (Nowak, Crane, and Stevens 2006), rainfall interception (Seitz and Escobedo 2011), as well as cooling through shade provision (Lin and Lin 2010) and evapotranspiration (Moss et al. 2019). The total leaf area provided by Derby's trees was 52.2 km^2. **Derby's urban tree species which provide the most leaf surface area are lime spp., sycamore, and black poplar; 15%, 12% and 9% of the total respectively (Figure 8)**. The genera with the greatest leaf area are maples, Leyland cypresses, then plums/cherries. Importance value[1] is calculated in i-Tree Eco from leaf area and population size, as an indication of which tree species within an urban forest are contributing most to ecosystem service provision. Thus, trees with large leaves and/or dense canopies tend to rank highly. The top tree species in the Derby study, by importance value, are sycamore (large leaves and abundant), lime spp. (large), followed by Leyland cypress (very abundant). The top Derby tree genera for importance were maples (abundant), limes (large and abundant), then ash (large).

1. A list of the importance values for all tree species encountered during the study is presented in Appendix II: Table A2.

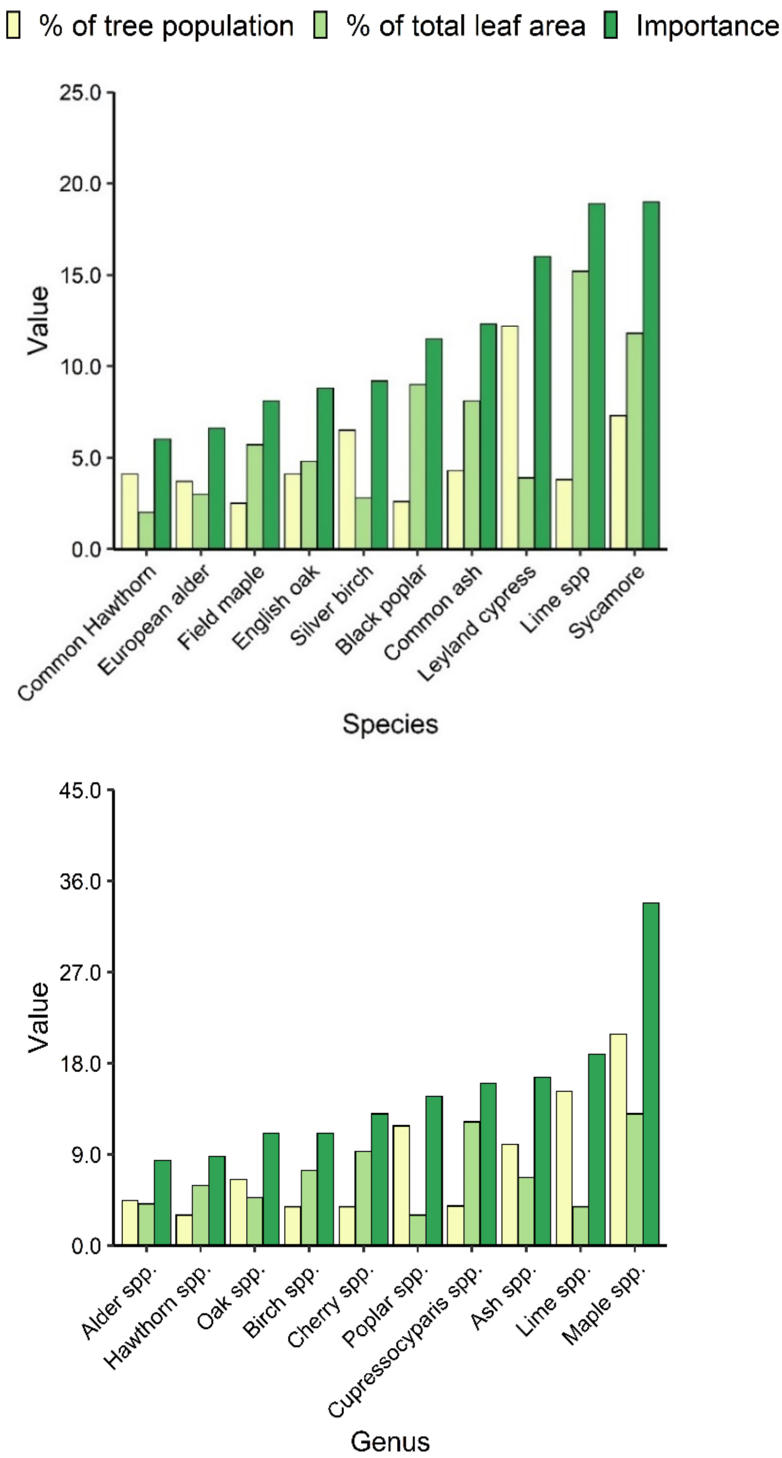

Figure 8. Top ten importance values in Derby by species (top) and genera (bottom), along with their percentage contribution towards total population and leaf area.

i-Tree Eco Importance value

Importance value is a measure of diversity. It is related to the dominance of species and is calculated as the sum of the percentage leaf area and percentage population. A high importance value therefore indicated that these species currently dominate the urban forest structure. This information may (and should) influence species selection in planting strategies to reduce reliance on overly dominant species to improve diversity and reduce the risks posed by pests and diseases. Other methods of assessing diversity should be used in combination with this metric to inform such decision making, including measures of richness (the number of species recorded), and evenness (the spread of population across

Ecosystem Services

Avoided Surface Water Runoff

The issue

Flooding is a serious concern for many towns and cities in the UK, causing property and infrastructure damage, mortalities, as well as morbidity from injury, transmissible diseases, and stress (Twigger-Ross 2005). Urban areas can be particularly vulnerable to surface water flooding, where rainfall may be unable to drain away due to high coverage of impervious surfaces, or because the infrastructure is out-dated. The Derbyshire region has recent experience of floods from high winter precipitation (Table 1).

How trees can help

Trees can ameliorate this problem by intercepting rainwater, and retaining it on their leaves and bark, until absorption or evaporation. The roots of trees can also increase natural drainage with water absorption, via capillary action and adhesion, until storage or release during evapotranspiration. Evidence shows reduced forest cover equates to greater stormwater flow volumes (Booth, Hartley, and Jackson 2002). This is particularly important for situations where the surface around the trees is permeable, allowing the water to infiltrate into the soil instead of flowing into the drainage system (although this is not calculated within i-Tree Eco).

Derby's trees

Derby's trees intercept an estimated 81,090 m^3 of water per year. This equates to nearly 125 of Derby Queen's Leisure Centre's gala pool[1]. Based on the standard local rate charged for sewerage[2], this saves £79,728 in avoided sewerage charges across Derby each year. By individual tree species, limes intercept the most water (12,162 m^3 per year), worth some £11,957 in avoided sewerage charges (Figure 9). Limes' importance to Derby is because of their large canopies, and relative abundance; their standing here is noteworthy because across five other Eco studies (see Methods) sycamore, common beech, English oak, and common ash were the leading interceptors.

1. [Poolfinder | Queen's Leisure Centre (swimming.org)] leisure/gala 25*13*25 m = (650 m^3)
2. Severn Trent sewerage cost of £0.98 per m^3 for the East Midlands in 2021/2.

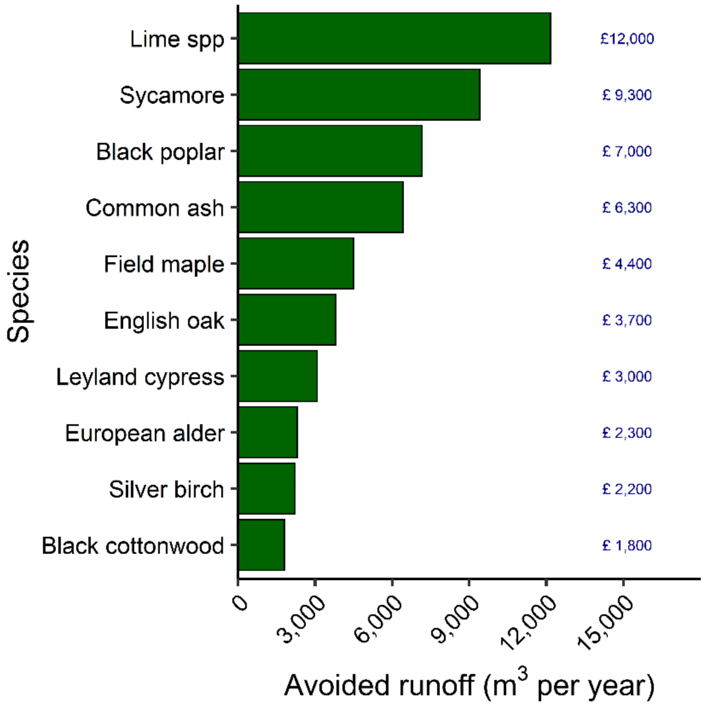

Figure 9. Volume of avoided surface water runoff per year provided by urban trees in Derby, and their associated value in avoided water waste sewerage costs[1].

1. Severn Trent sewerage cost for the East Midlands in 2021/2.

Reducing flooding in Derby

Due to climate change, the UK is bracing to experience increasingly rainy winters with more storms. This increases the risk of flooding and is exacerbated by the vast amount of impermeable surfaces in urban areas such as roads and buildings which drain water directly into rivers.

Derbyshire is criss-crossed by a network of rivers, the largest of these being the River Trent. The City of Derby is located along one of its main tributaries, the River Derwent. The areas natural geography makes it liable to river flooding, and the urban centre of the city has struggled with surface flooding in the past.

The 'Derby City Council Local Flood Risk Management Strategy' (2017) recognises that the most frequent flood risk in Derby is flooding from heavy rainfall, which can often happen and quickly impacts a number of high risk properties, and that surface water flooding is made worse in the city by:

- Changes to surfacing due to loss of gardens or reuse of brownfield sites.
- Large urban areas of impermeable paving or tarmac.
- Soils, such as clay, that do not easily allow water to pass through them.

It also notes the risk of pollution in watercourses which can occur due to run-off from roads, agricultural land, and overflowing sewerage/drainage systems during heavy rainfall events. In the future, the need for new housing will place additional pressures on greenfield land in and around Derby, which may put additional pressures on flood defences. Preventative management strategies should include tree planting initiatives to reduce surface runoff and ease pressures on drainage systems. These should include informed species choices to maximise canopy interception.

This issue can be difficult to combat, and river catchments rarely confine themselves to administrative boundaries, therefore collaboration with those both upstream and downstream is key to making the most impact. Tree planting can be most effective in the mid and upper regions of rivers, along tributaries and in cities along the length of the river course. In the lower reaches of the river, on flood plains, interception is less vital and increasing percolation rates becomes the top priority to allow the land to drain after a flood has occurred.

Air Pollution Removal

The issue

Common air pollutants include NO_2, SO_2, O_3, CO, and $PM_{2.5}$; their release is proportional to fuel combustion, with type of fuel, environmental conditions, and mitigation measures influencing the relative abundance of each component. In turn, fuel use is high in urban areas which have greater energy demand and traffic (Duh et al. 2008). Generally, pollutants irritate and impair respiratory, cardiovascular, or both, systems (Manisalidis et al. 2020). NO_2 and SO_2 also damage flora and infrastructure which are susceptible to acid rain (Burns et al. 2016). Chronic exposure to air pollutants is linked to morbidity and death; in the East Midlands nearly 2,000 deaths are attributed to air pollution (Table 1).

How trees can help

Plants absorb air-borne pollutants through their stomata, or simply intercept pollutants which are deposited on their surfaces (Escobedo et al. 2008; Nowak, Crane, and Stevens 2006). This leads to year-round benefits, with bark continuing to intercept pollutants throughout winter. Plants also cool local temperatures by shading and evapotranspiration, this reduces the formation rate of some air pollutants, such as O_3 (Jacob and Winner 2009). However, trees can also contribute to O_3 production by emitting volatile organic compounds (VOCs). VOCs can react with other pollutants such as NO_x emitted by vehicle exhaust fumes (Lee et al. 2006). i-Tree Eco takes the release of VOC's by trees into account to calculate the net difference in O_3 production and removal.

Derby's trees

It is estimated that **Derby's urban trees remove 60 tonnes of airborne pollutants, annually**. **This service to society is valued at £278,200, annually**. The pollutants include O_3, NO_2, $PM_{2.5}$, SO_2, and CO, in descending order of removal (Figure 10). Air pollution removal was especially effective in summer, with the mean value for that month being at least double the average of other seasons (Figure 11). The pattern of air pollutant removal by Derby's urban forest broadly matches five previous UK i-Tree studies (see Methods); with removal of O_3, of NO_2, and removal during summer, being particularly important. NO_2 is the most critical air pollutant in Derby, and $PM_{2.5}$ is of national concern. Both pollutants are caused in part by transport.

In both the USA and the UK, pollutants are valued in terms of the damage they cause to society. However, the damage valuation methods are different across countries: for example United States Externality Costs in the USA (USEC), and Social Damage Costs (UKSDC) in the UK. The UK valuation method does not cover all airborne pollutants, such as CO and O_3; because of the uncertainty associated with the value of removing some airborne pollutants, because the value of some pollutants can vary depending on their emission source, or because the SDC has not yet been determined by the UK Government.

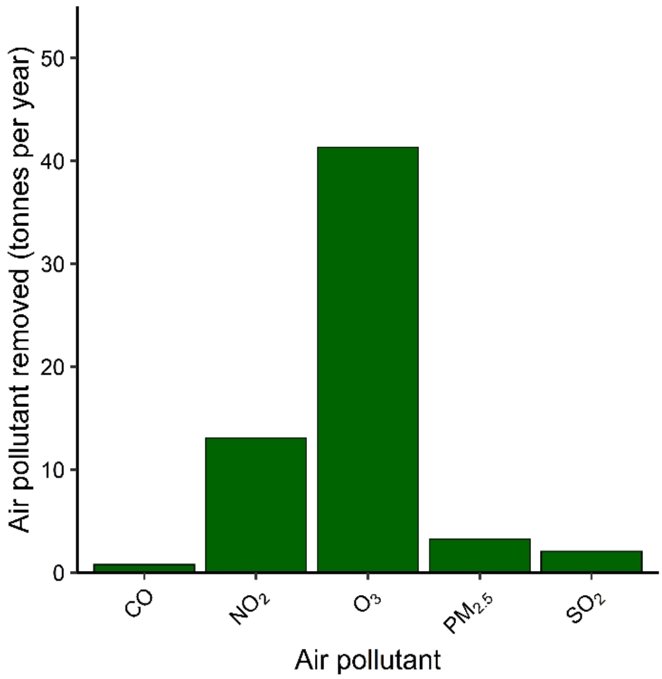

Figure 10. Annual sum of the mean monthly quantity of atmospheric pollutants removed by urban trees in Derby.

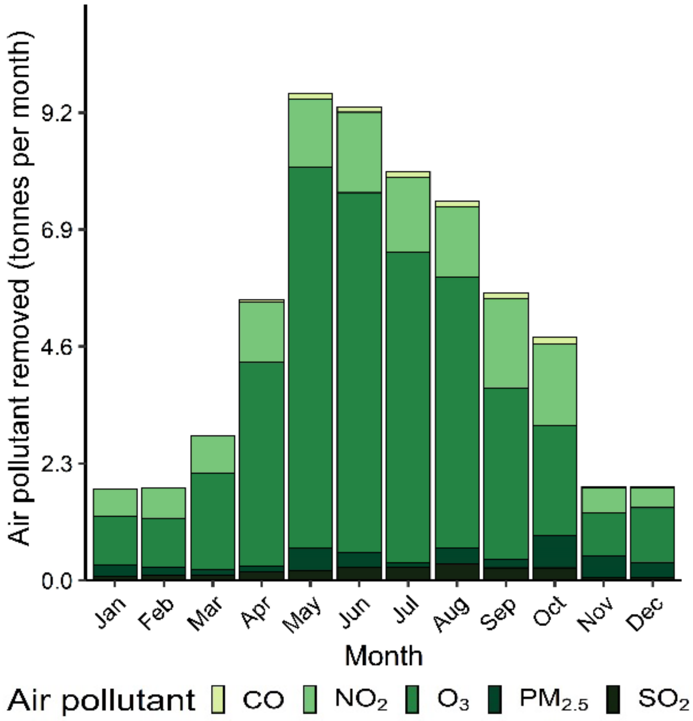

Figure 11. Amount of atmospheric pollutants removed by Derby's urban trees on a monthly basis.

Air pollution removal by Derby's urban trees

Derby City Council have declared two Air Quality Management Areas (AQMAs) covering the inner and outer ring roads and a section of the A52 around Spondon (boundaries are subject to change), as a result of high levels of NO_2 produced by road traffic. A review of air quality monitoring locations is undertaken annually, and under the Local Air Quality Management (LAQM) regime, the main air pollutants of concern in Derby continue to be nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$).

Tree canopy cover is not currently part of the measures to improve air quality as outlined in the 2021 Air Quality Annual Status Report (ASR); in fact there is no reference to trees within this document. Given the clear benefits of trees with regards to air quality, it is a logical and sustainable long-term solution to a serious problem within cities, particularly in those with high population density and an industrial heritage. Targeted tree planting can help achieve aims and objectives within the three priorities of the Air Quality Action Plan (AQAP); tackling NO_2 hotspots, improving the overall air quality across Derby, and managing airborne $PM_{2.5}$ exposure. Many of the actions recommended by the AQAP, the Low Emission Strategy (LES), the Local Roadside NO_2 Plan, and others focus on reducing air pollution emissions. Planting trees along transport corridors and within the most affected areas can remove emissions which may be deemed 'unavoidable'. This can have many benefits beyond cleaner air, as often the most at-risk areas are those which also have higher levels of deprivation. Greening these areas can improve health and wellbeing, decrease crime rates, improve the amenity of areas and increase property value.

The amount of pollution trees can remove is directly linked to leaf area, so species selection for larger trees with higher leaf area is a key consideration for a planting strategy aimed at cleaner air. It is also important to consider that though conifers and other evergreens usually have less leaf area than broadleaf species, evergreens continue to remove pollution all year round, unlike broadleaves. In order to keep air quality high through the winter months, some evergreen species should be included in any planting mix. Planting location can also have a huge impact on the success of a clean air strategy. If trees are in the wrong place, too close together, or all the same height, then pollution can get trapped beneath the canopy, particularly along transport corridors and in cities where buildings channel and block the wind. To combat this, careful planning of tree spacing and of different ages is vital.

Carbon Storage and Sequestration

The issue

CO_2 is the second most abundant greenhouse gas, after water vapour. Greenhouse gases are relatively complex atmospheric molecules which absorb and re-emit infrared heat rising from the Earth's surface. Since pre-industrial levels, the atmospheric CO_2 concentration has increased by at least a third to over 400 parts per million (Intergovernmental Panel on Climate Change 2014). Correspondingly, the average global temperature has risen by approximately 1ºC. Consequent issues which the UK will face are likely to include: increased frequency and intensity of extreme weather like heatwaves, fires, and floods, as well as pressure on food supply, biosecurity, and biodiversity. Derby CC monitors its carbon footprint, with the aim to reduce it (Table 1).

How trees can help

The urban forest is an important repository for carbon, both with respect to the total amount of carbon stored as well as the annual sequestration rate. Carbon storage is the accumulated quantity of carbon bound up in trees' woody material above and below ground. Annual Carbon Sequestration is rate of carbon storage; the amount of carbon (in the form of carbon dioxide) removed from the atmosphere through photosynthesis over a year. By absorbing CO_2 from the atmosphere, photosynthesising, and locking carbon within woody tissues, trees help to combat a key driver of climate change. Consequently, large trees with dense wood act as bigger carbon stores, while fast growing trees sequester more carbon annually (Kirby and Potvin 2007; Smith, Dearborn, and Hutyra 2019) Across a city net carbon sequestration can be negative, if emission from decomposition is greater than uptake by growing trees.

Derby's trees

It is estimated that **Derby's urban forest stores a total of 106,825 tonnes of carbon in its wood, above and below ground**. This is equivalent to 391,692 tonnes of CO_2, which is comparable to the emissions produced by 78,338 households, around 70% of the number of properties in Derby[1], or alternatively, the annual CO_2 emissions of 243,282 cars[2].

1. Based on an average UK household emission of 5 tonnes of CO_2 per year in 2012 (Palmer and Cooper 2013), and 111,780 properties estimated in Derby in 2021 (Derby City Council 2021d). Note, the ratio of mass of C to CO_2 is 12:44.
2. Based on average emissions of 122 g of CO_2 per km (cars after April 2015, Department for Transport, 2015), with the average UK car travelling 13,197 km per year (Department for Transport 2013). Note, the ratio of mass of C to CO_2 is 12:44.

The relative amount of CO_2 stored is toward the low end of five previous UK i-Tree studies (see Methods), for example Cardiff's tree carbon store is equivalent to the emissions of 140% of its households.

Similar to leaf area, carbon storage depends on a variety of factors including the number, species, size, and health of the trees present. Moreover, timber density and quality is important. Larger trees store more carbon in their tissues; limes, for example, make up 4% of Derby's estimated urban tree population, but store 19% of the total carbon, Leyland cypresses on the other hand, make up 12% of the tree population, but only store 8% of the carbon (Figure 12).

The carbon in trees can be valued within the framework of the UK government's carbon valuation method (DBEIS 2021). This is based on the abatement costs of meeting the UK's carbon reduction targets. These social values of carbon are split into two types: traded and non-traded. Traded values are only appropriate for industries covered by the United Kingdom Emissions Trading Scheme, introduced January 2021. Carbon storage or sequestration by trees does not fall within this category so non-traded values are used instead. Within non-traded values, there are three pricing scenarios: low, central, and high. These are used to reflect uncertainties in determining future carbon values, including in relation to future fuel prices. Based on the central value for non-traded carbon for 2020, it is estimated that the carbon in the current tree stock is worth £ 95.9 million.

Taking into account 685 tonnes of released carbon, from sources like decomposition of dead trees and leaf litter, Derby's urban forest is estimated to sequester 3,233 tonnes of carbon per year, net (Figure 12); this estimated amount of carbon is worth £2,903,234. The net sequestration rate is equivalent to the estimated annual emissions of 2,371 households, or instead, the annual emissions from 7,363 cars.

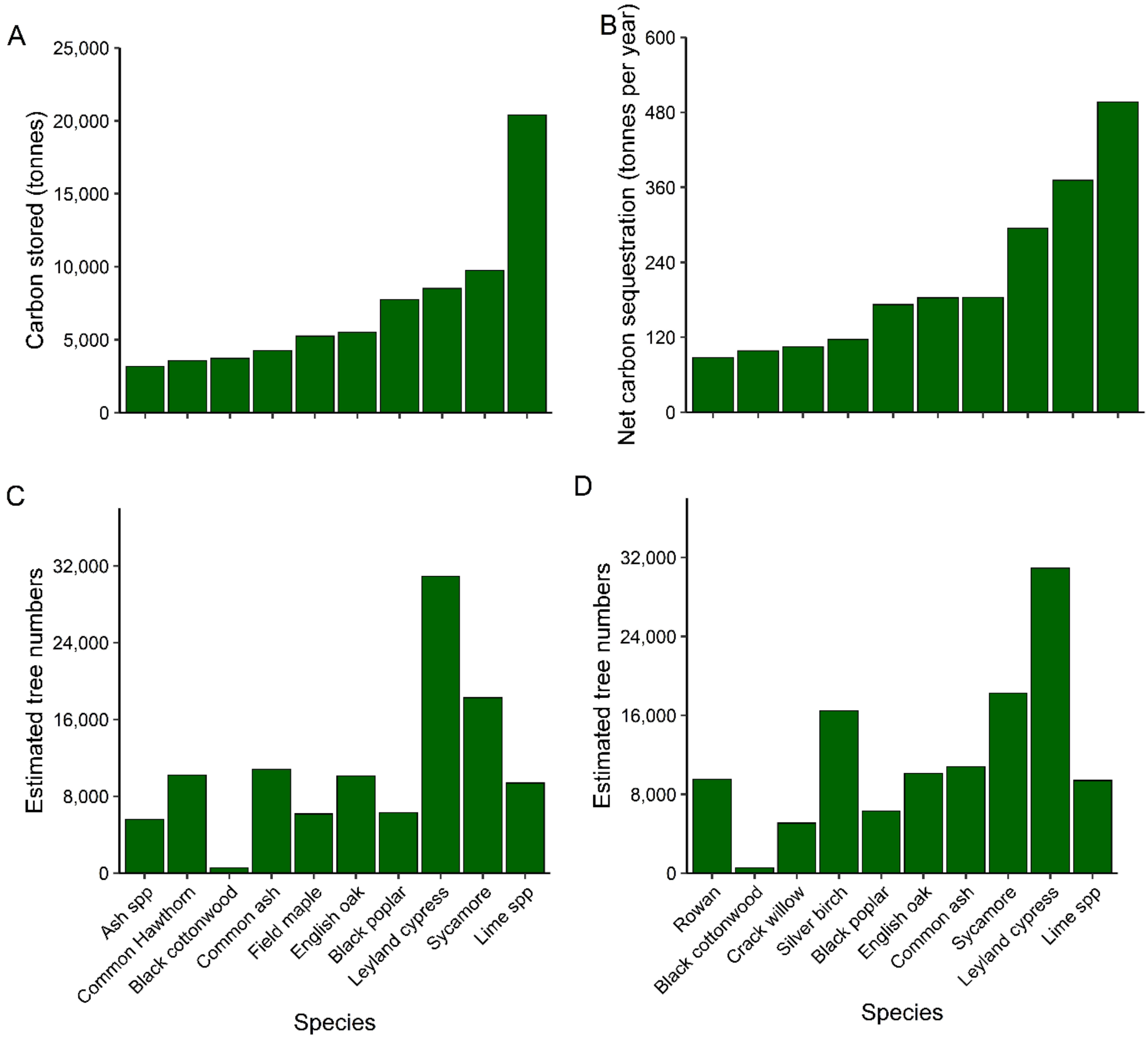

Figure 12. Carbon stored (top left) by the top ten species responsible for this storage and their estimated abundance (bottom left) in Derby's urban forest. Net carbon sequestration (top right) by the top ten species responsible for this sequestration and their estimated abundance (bottom right) in Derby's urban forest. Tree abundances estimated by i-Tree Eco.

Carbon Storage and Sequestration

Trees have the ability to sequester CO2 through photosynthesis, and store carbon in soil and in plant biomass; approximately 50% of a tree's dry weight is carbon. Green areas in cities can significantly reduce the atmospheric concentration of CO2, and can indirectly reduce carbon emissions by offering shading in the summer and insulation in the winter.

Across any area, the amount of carbon sequestered is influenced by the number of trees and their spatial coverage, the age and health of trees, their rate of mortality, their interaction with soil, and the disposal/use of trees at the end of their life. Naturally, the more trees and the more area they cover, the more carbon will be sequestered. Trees sequester carbon at different rates throughout their lifetime; young trees grow quickly and therefore the rate of sequestration is increased. As they mature, the growth rate reduces, as does the rate of sequestration. It is important to keep the population diverse in age and size to maintain sequestration and storage rates when some trees die or are felled or new trees are planted as replacements, and reducing the mortality rate of trees will help in this aspect. Approximately 20% of a tree's biomass is below the ground in root systems which can transfer nutrients too and from the surrounding soils, trapping carbon compounds. Additional carbon is stored when leaves fall in autumn, however often in cities the leaves are not given a chance to break down in-situ and therefore this opportunity is not maximised; composting can be a vital carbon sink and can increase soil health.

Carbon storage and sequestration are part of a wider cycle. In order to ensure that the trees in Derby are having a positive impact in reducing global atmospheric carbon, they must sequester more carbon than is given off. The cycle extends far beyond the life of the tree, and carbon must be stored for as long as possible. If trees being removed are disposed of in a poorly managed way, the carbon which has built up over the lifetime of the tree can be instantly returned to the atmosphere (for example if the trees are burned). Converting dead or felled trees into lumber or wood products can vastly extend the amount of time carbon is stored for. Wood products can also indirectly reduce carbon emissions by acting as a replacement for a less eco-friendly product made of, for example, plastic or metal.

Habitat Provision

The issue

Biodiversity is threatened by global change pressures like habitat loss, over harvesting, invasive species, and climate change. For example, it has been predicted that up to 40% of species will be 'committed to extinction' by climate change before 2050 (Thomas et al. 2004). Recent observations are not reassuring, a study monitoring invertebrate abundance in Europe, found it had declined by 80% over 27 years (Hallmann et al. 2017). Consequently, there are potentially grave consequences for the resilience of ecosystem functions on which humans depend. Research looking at 4,424 species in Great Britain over 40 years, found that significant net declines in animals which provide pollination, pest control, and cultural values (Oliver et al. 2015).

How trees can help

Globally, it is predicted that urban areas would have spread 1.4 times their extent between 2012 and 2050 (Zhou, Varquez, and Kanda 2019). Despite their increasing landscape dominance, urban areas can be relatively fragmented and hostile for biodiversity, by reducing suitable habitat availability and connectivity, in turn impacting on the resilience of natural populations (Fenoglio et al. 2021; Hill et al. 2008; Parmesan et al. 2015).

Trees can mitigate the hostility of urban areas, by creating habitats which other flora and fauna use (Nielsen et al. 2014; Sales, Gardner, and Kerr 2016; Smith et al. 2006). Native trees are thought to better sustain native biodiversity (Kendle and Rose 2000). For example, native oaks support approximately 2,300 species, including 1,200 invertebrates, 40 birds, 30 mammals, 200 plants, and 800 fungi (Larner, Rynne, and McLaughlin 1992; Mitchell et al. 2019). However, non-natives can also be beneficial for nature, especially in urban areas where native trees may not always be suitable (Sjöman et al. 2016). In particular, non-native species can be important food sources for pollinators (Baldock et al. 2015). Larger and older trees have been found to harbour greater biodiversity (Carr et al. 2018; Nielsen et al. 2014). Overall, a diversity of trees is most important, with a range of tree species, ages and sizes offering the greatest range of possible habitats (Nielsen et al. 2014).

By promoting urban biodiversity, ecosystem service provision is improved. For example, conserving wildlife retains opportunities for people to view and interact with nature, this connection is linked to improved health and wellbeing (Nghiem et al. 2021), and understanding of the natural world (Miller 2005).

Derby's trees

The biodiversity value of Derby's trees was assessed using data on a range of metrics from literature, and the urban forest composition. This analysis provides an indicator of the relative value of tree species, and their population size in Derby. Large populations of trees which have low biodiversity value may indicate opportunities for changes in the composition of the urban forest to improve its value to wildlife. One metric was Alexander, Butler and Green's (2006) review which scored trees from high value (5) to low value (0) for providing pollen and nectar as well as fruits and seeds. Another metric was the number of invertebrates associated with tree species from Southwood (1961) and Kennedy and Southwood (1984). While these metrics provide a useful indicator of the relative biodiversity value of different trees, it is important to note that the underlying data vary in time, space, and methods, and may not be specific to urban forests.

Biodiversity values were assessed for three aspects of biodiversity: foliage invertebrate richness (Figure 13), as well as blossom and pollen provision, and seed and fruit provision (Figure 14). The figures illustrate the values of different species, but generally show that many of Derby's larger tree populations provide high levels of biodiversity value. It also identifies potential species for future planting which could be considered to provide biodiversity value.

Derby harbours a Site of Special Scientific Interest and the largest UK rewilding project (Table 1). **Of the tree species considered, the most abundant taxa in Derby are not necessarily the best for supporting insects**. For example, sycamore are the most abundant, 7.2% of the tree community, but only supports 43 insect species; whereas blackthorn, 0.7% of the tree community, supports 153 insect species. (Figure 13). To improve habitat provision to insects, one may consider in future increases the number of trees for groups like willows and oaks instead of sycamores and cypress.

Two of the three most common tree genera in Derby rank relatively high in the provision of nectar/pollen; maples and plums/cherries. Increasing the proportion of hawthorns, willows, whitebeams, and limes may improve this service. **Similarly, the second and third most common tree genera are rated highly as providers of seeds/fruits; plums/cherries and oaks** (Figure 14). To enhance this food source, one may consider more hawthorns, whitebeams, and alders, in future. Note that the cherry/plum, whitebeam, and hawthorn groups perform well as supplying nectar/pollen as well as seeds/fruits.

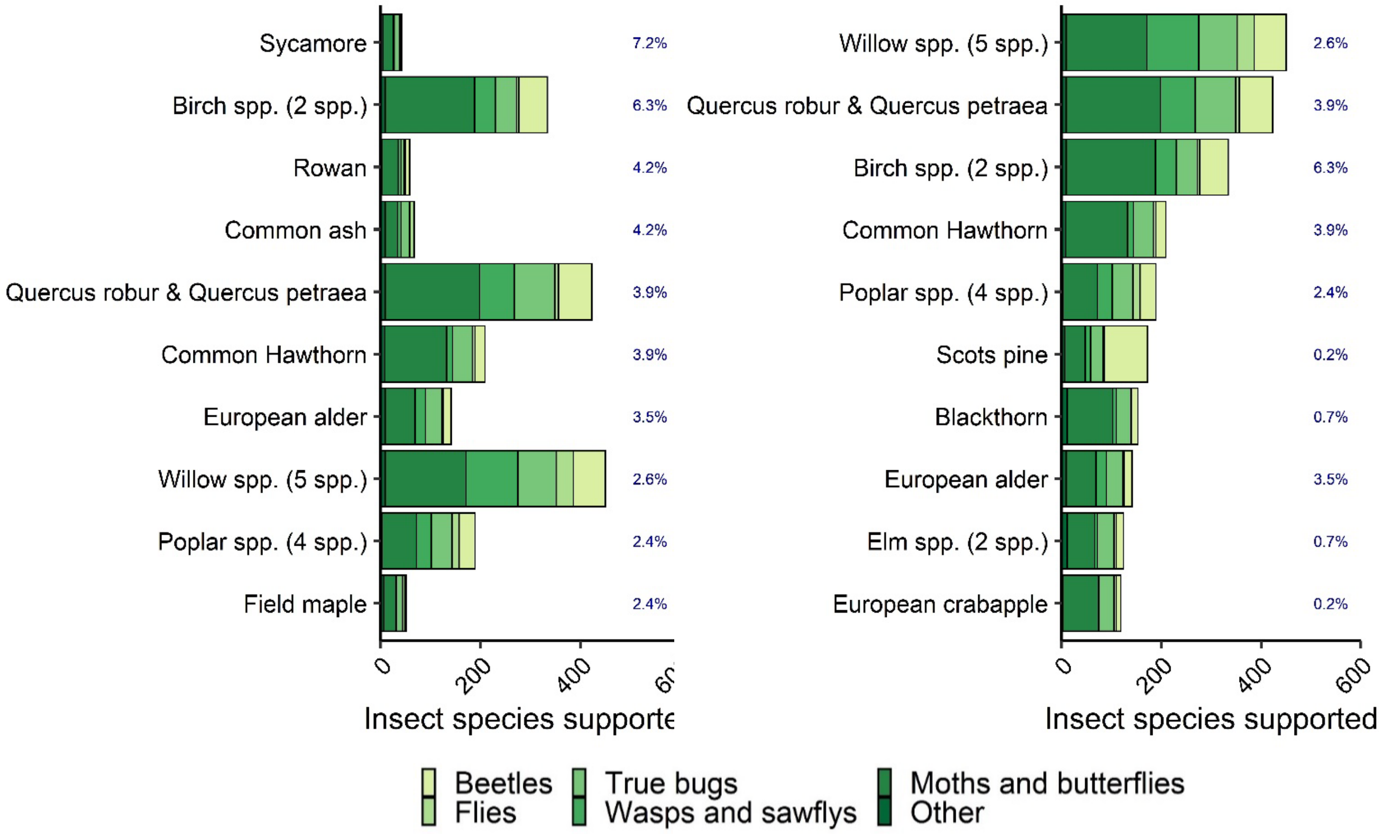

Figure 13. The number of insect species supported, by the ten tree species with the highest relative abundance (left), or which support the greatest richness of insect species (right). Percentage value in blue indicates the abundance of each tree species relative to the tree population. Only the tree species with available insect species supported data are included. Data here are the upper estimate, or idealized, species support. Not all species may be present in Derby, for example due to climatic reasons.

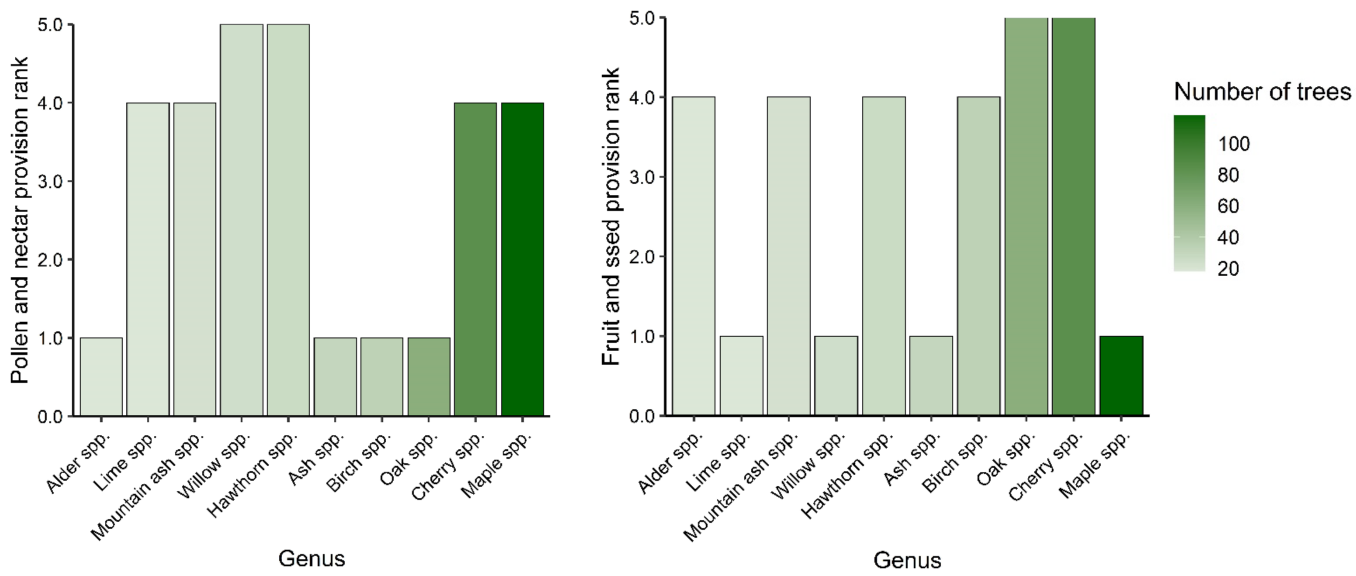

Figure 14. Provision ranking for the ten most populous genera for pollen and nectar (left), as well as fruit and seeds (right); where a rank of five indicates relatively high food provision. Food provisioning described here is mainly mutualistic (co-operative between trees and insects). Tree species with a low provisioning here may hold a large quantity of available biomass in structures like foliage and roots for herbivorous consumption.

Replacement Cost and Amenity Value

CTLA Valuation

The **urban forest of Derby has an estimated replacement value of £244 million according to the CTLA** Appraisers' (1992) valuation method. This is the cost of replacing the urban forest of Derby should it be lost. Physical factors like species, diameter, condition, and location influence this value, for example large and numerous trees would be more expensive to replace. This calculation does not account for amenity value.

CAVAT Valuation

The urban forest of Derby has an estimated public amenity asset value of £1,020 million according to CAVAT Adjusted Quick Method valuation, which takes into account the size, accessibility, and health of trees as well as their public amenity value. **The maple (*Acer*) genus had the highest overall amenity value in Derby, which contributed to 30% of the urban forest's value** (Table 9; Figure 15). The next largest contributors were poplars (*Populus*), followed closely by oaks (*Quercus*); both had values which were less than half of maples. The single most valuable tree encountered in the study was a 15 m high English oak (*Quercus robur*) in excellent condition on an agricultural border in North Spondon; it was estimated to have a CAVAT asset value of £112,176. The high amenity (structural and functional) value of maples, poplars and oaks was unsurprising; because they are relatively abundant and healthy in Derby, and generally tend to have large statures and long lives.

Considering the top three positions for amenity value across five previous UK i-Tree studies (see Methods), maples, poplars, and oaks appear in four, one, and three, of the reports, respectively. Derby's total CAVAT amenity value is low, and its most valuable tree is mid table, when compared to these studies.

The land use type containing the highest CAVAT value of trees was residential, with 43% of the total value of the trees, and an estimated value of £575,782. This equates to £311 million when extrapolated for the whole of Derby. Parkland and golf course were the next most important contributors for the CAVAT value (Figure 15). The importance of residential land for the amenity value of Derby's trees is noteworthy, as across five past UK i-Tree studies, residential is typically comes second or third. Previous i-Tree Eco studies, and pan-city CAVAT valuation studies, find that trees on parks and cemeteries often return a high contribution to total public amenity.

Table 9. CAVAT amenity value for the top ten most valuable tree genera.

Genus	Value of measured trees (£)	Value extrapolated across Derby (£)
Maple	570,051	308,805,848
Poplar	229,190	124,155,757
Oak	226,185	122,528,156
Willow	172,280	93,326,589
Cypress (*Cupressocyparis*)	97,022	52,558,409
Yew	80,058	43,368,683
Ash	80,017	43,346,697
Lime	76,234	41,297,031
Hawthorn	51,797	28,059,403
Birch	49,076	26,585,160

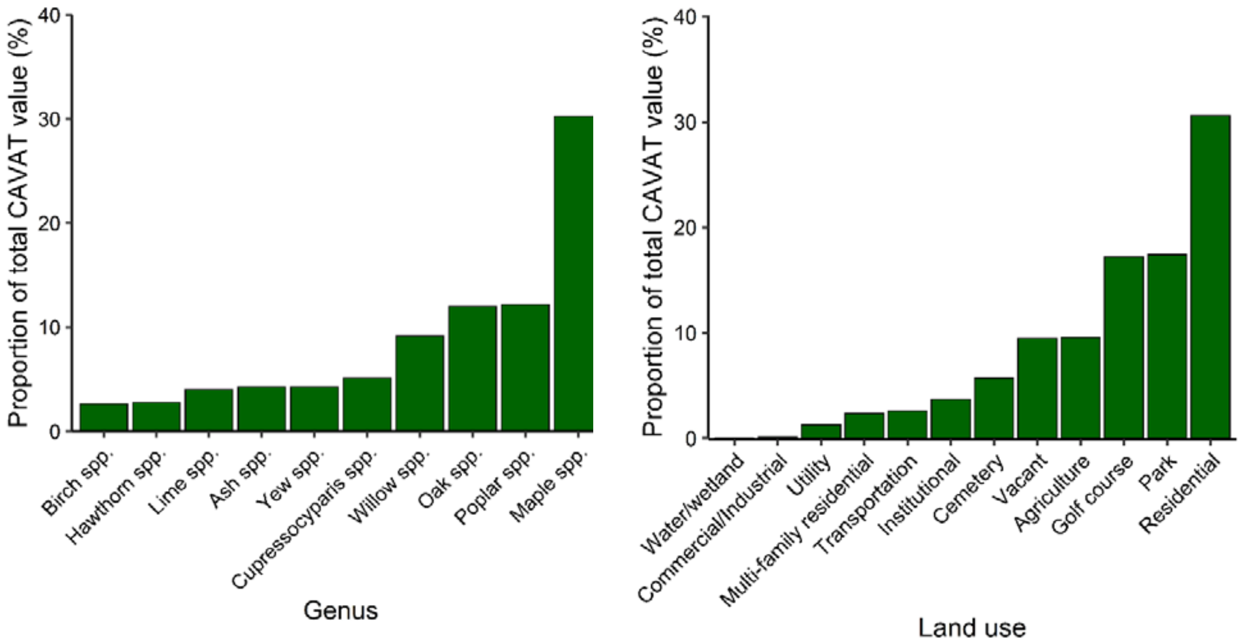

Figure 15. The top ten genera according to CAVAT valuations, and their relative contributions of each component, for the top ten most valuable genera (left), and across land uses. Land uses were defined by the dominant function in each plot.

The value of amenity trees

The value of trees to people goes beyond their material worth; their beauty should not be overlooked. While some trees in cities may be planted with a purpose such as improving air quality or providing shade cover, some are planted simply because they look nice. Usually these 'amenity trees' are planted in private gardens or parks, and may be ornamental species or exceptional specimens of large-structure trees. Derby City Council looks after 300 parks and open spaces across the city, covering 700 hectares, which are prime areas to target with amenity trees.

Amenity value is different to replacement cost. Replacement cost is a CTLA, or like for like, valuation of the cost to replace a tree with another identical tree, including price of purchase and planting, years of management, etc. Amenity value is a price put on how attractive a tree may be, and how it impacts the lives of people who see it. It varies depending on species, age, size, condition, location, etc.

Pests and Diseases

The issue

Animal pests and microbial pathogens are a serious threat to urban forest health. First, they generate direct economic costs as a result of damage and mitigation measures. For example, Kew Royal Botanic Garden's (2017) State of the world's plant report highlights that globally, the annual spend on insecticides is over US$15 billion and that in the US, introduced diseases have effectively eliminated entire tree species in a decade. Single pests can be very damaging, the emerald ash borer (*Agrilus planipennis*), could cost USA's urban forest up to $300 billion (Poland and McCullough 2006).

Second, the reduced health of trees impacts on their ecosystem service provision. For example, research found that through killing trees and altering communities, carbon storage and sequestration are reduced and soil fertility decreases (Kew Royal Botanic Garden's 2017). The ecosystem service loss can be extreme; modelling of the mountain pine beetle's (*Dendroctonus ponderosae*) impact on British Columbia suggests it reduces the amount of carbon sequestered, equivalent to four years' worth of Canada's CO_2 emissions (Landry et al. 2016).

In the UK, the urban forest community has changed in living memory, with Dutch Elm Disease killing approximately 30 million trees in the UK since its arrival in the 1960s (Webber 2010), and the recent expansion of Chalara ash dieback. The pressure on UK forests is predicted to increase. First, from elevated global trade plants and plant materials such as timber. For example, a recent Asian longhorn beetle (*Anoplophora glabripennis*) outbreak in southern England was via untreated wooden pallets (Straw et al. 2016). Second, through climate change, as summarised in a review by Wainhouse and Inward (2016). Generally, global warming can increase tree vulnerability through more frequent and intense drought and storm damage. Simultaneously, rising temperatures are favourable for many invasive species facilitating their spread and their annual generation number.

Pests and Diseases in Derby

Considering the impacts of tree diseases, and its exacerbation by global change, assessing the risk pests and pathogens pose to urban forests is paramount. A risk matrix was devised for determining the potential impact of a pest or pathogen, should it become established in the urban tree population of Derby on a single genus (Table 10) and for multiple genera (Table 11). **This informed Table 12,**

which gives an overview of the existing and emerging risks for Derby's urban forest. The tables present the proportion of the Derby's urban forest community at risk from each pest or pathogen, and the associated amenity value of these trees.

The UK plant risk register contains 1,240 entries. A focus has been given to a subset of agents which lead to the death of the tree, or pose a significant human health risk. Likewise, emphasis has been given to tree species which are abundant in Derby. Additional examples ample hosts in Derby, but relatively low unmitigated risks, include: Nassonov's mealybug (*Planococcus vovae*), which affects cypresses; Rowan ringspot associated virus; and Gypsy moths (*Lymantria dispar*), which defoliate a range of broadleaf trees; and *Xanthomonas arboricola pv. pruni*, which spoils stone fruits. Chalara ash dieback has been reported in greater detail in the subsequent section, and further information on individual pests and diseases is provided in Appendix III. Information has primarily been drawn from the UK Plant Health Risk Register (DEFRA 2022b), and Forest Research pest and disease webpages (Forest Reserach 2022).

Table 10. Risk matrix used for the probability of a pest or disease becoming prevalent in Derby's urban forest on a single genus

Prevalence	% of Community		
	0-5	6-10	>10
Not in UK			
Present in UK			
Present in Midlands			

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

Prevalence	% of Community		
	0-25	26-50	>50
Not in UK			
Present in UK			
Present in Midlands			

Table 12. The significance of a range of existing and emerging pests, pathogens, and diseases to Derby's urban forest.

Pest/Pathogen/ Disease	Major tree species hosts affected	UK Relative Risk Rating Rank[1]	Continued Prevalence in the UK	Prevalence in England	Risk of spreading to England	Urban forest population at risk (%)	CAVAT value of trees (£)[2]
Acute oak decline	*Quercus* spp. including *Q. ilex, petraea, robur*	47	Limited	Central and South East	High – already present	**4.4**	123 million
Asian longhorn beetle (*Anoplophora glabripennis*)	Many broadleaf species (see Appendix III)	25	Absent	A contained outbreak in the South East	Medium – climate change, trade	**44.9**	626 million
Two-lined chestnut borer (*Agrilus bilineatus*)	*Castanea dentata* *Quercus* spp. including *Q. robur*	12	Absent	Absent	Medium – climate change, trade	**3.9**	102 million
Bronze birch borer (*Agrilus anxius*)	*Betula* spp. including *B. pendula, utilis*	12	Absent	Absent	Medium – climate change, trade	**7.2**	27 million

Emerald ash borer (*Agrilus planipennis*)	*Fraxinus* spp. including *F. americana, excelsior*	3	Absent	Absent	High – suitable climate, trade	**6.6**	43 million
Oak processionary moth (*Thaumetopoea processionea*)	Quercus spp. including *Q. petraea, robur*	12	Limited	Greater London and locally in home counties	High – already present	**4.2**	104 million
Ramorum disease (*Phytophthora ramorum*)	Over 150 plants (see Appendix III)	3	Limited	Western side, especially south and north	High – already present	**33.0**	458 million
Alder bleeding canker (*Phytophthora alni*)	*Alnus* spp. including *A. cordata, glutinosa*	154	Widespread	Riparian areas throughout, especially in the south	High – already present	**3.9**	14 million
Phytophthora kernoviae	Many broadleaf species (see Appendix III)	12	Limited	Primarily South West	High – already present	**7.4**	139 million
Bacterial leaf scorch (*Xylella fastidiosa*)	Many broadleaf species (see Appendix III)	123	Absent	Absent	Medium – climate change	**21.4**	253 million

1. Rank out of 1240 agents on the UK plant health risk register, October 2022. First rank carries the greatest risk, where ties present, the median rank is provided. 2. Rounded to the nearest million.

Chalara Ash dieback

The ash's (*Fraxinus* spp.) large stature, low density canopy, and generalism across a range of soils and climates, means they are a prominent component of the UK landscape and ecosystem. They are important for resilience, being the group which supports the most species, of the 2,300 species associated with oaks (Mitchell et al. 2019). Furthermore, a number of invertebrates and epiphytes wholly depend on ash. Ash's timber is strong durable, flexible, and attractive so is valued by decorative and practical hardwood industries

Ash dieback is caused by the fungus *Hymenoscyphus fraxineus (*previously called *Chalara fraxinea*), it primarily targets common and narrow leaved ash. However, worldwide all 65 species of ash are thought to be somewhat susceptible to Chalara. Young and coppiced trees are particularly vulnerable, and can be killed within one growing season of symptoms becoming visible. Symptoms first appear in leaves and shoots, which blacken and fall from mid-Summer. If the infection spreads down stems dark lesions and cankers appear on the bark, often in diamond shapes around branch joints. Death is often from the trunk being girdled so that water and nutrient transfer to the canopy is blocked. *H. fraxineus* was first recorded in the UK in 2012 in Buckinghamshire. It is widespread across England with concentrations in the South, East and North West. It was first reported in Derby in 2018 (DEFRA 2022a). It has a relatively fast dispersal, with wind spreading spores tens of kilometres. Its spread is especially concerning considering possible interactions with other potential threats like honey fungus (*Armillaria*), and the emerald ash borer, which has caused billions of dollars of damage in the USA.

Amongst Derby's urban forest, ash is the 6th most common genus, with 6.6% of trees belonging within it. As the disease is present in the midlands, affects one genus, which is 6.6% of the community, it therefore has a red risk designation in Table 10. **Its loss would equate to £43 million in CAVAT amenity value, equivalent to 4% of the total**. The risk of Chalara on Derby's urban forest amenity was slightly below average, when compared to a range of previous studies; for example, it was lower than Cardiff (6%), London (7%), Burton-on-Trent (8%) but higher than Edinburgh (<3%) and Wrexham (<1%). With regard to the impact on other ecosystem services in Derby, common ash (*F. excelsior*) alone stores 3,189 tonnes of carbon and catches 6,421 m^3 of rainfall a year.

The abundance of ash across regions and wards has been provided in Appendix IV: Table A8. The region at greatest risk of Chalara was the South East, in which 9.5% of the population consisted of Ash trees (*Fraxinus* genus). The ward which could be most susceptible was Alvaston, in which 24% of the population consisted of Ash trees (*Fraxinus* genus).

Management to Reduce Risk

Increasing the resilience of the urban forest as a whole by diversifying the tree community may reduce the impact associated with some pests and diseases. Similarly, for diseases which are hard to contain, like Chalara ash dieback, research aims to identify and propagate variants with resistance (Kew Royal Botanic Gardens 2017). However, prevention is often better than management. Some pests and diseases are not currently present in the UK, such as the Asian longhorn beetle, the three *Agrilus* borers, and *Xylella fastidiosa*, which are listed in Table 12. These emerging risks have the potential to damage many species and disrupt urban communities. Diseases can reach the UK naturally, such as being windblown or flying over the channel, however, the import of plants and plant products is a gateway. Consequently, in order to protect urban forests from all pests and diseases, vigilance is key. Monitoring urban trees for signs of pests and diseases helps trigger a fast response to eradicate them before they are a problem, as well as informing research targeted at combating diseases in the long term. The UK Plant Health Risk Register (DEFRA 2022b) provides predictions for each species for a business as usual scenario, and one with mitigation measures in place. The Forest Research pest and disease webpages provide specific information for each disease on how to monitor for it, and limit its spread (Forest Research, 2022).

Location comparisons

Derby's Regions

To aid local interpretation of Derby's i-Tree Eco data and designing actions arising from the study's findings, survey data was stratified into four regions (Figure 2; Table 14). The four regions were North (6 wards), Central (0.5 ward), South East (4 wards), and South West (6.5 wards) (Appendix IV: Table A3)

The North, South East and South West regions of Derby were largely comprised of residential land uses, with relatively low proportions of multi-family residential buildings. The South East region had a high proportion of rural land uses such as golf courses and agriculture. In contrast, the Central region contained more built-up areas of the city with commercial and industrial land uses dominating.

The stratification allowed for a quantification of some of the ecosystem services provided by the trees located in the four regions, and their respective values. These differences are listed in Table 14. **Due in part to its larger area, the North section holds the largest proportion of Derby's trees. The North region also has a higher density of trees than the other regions. The population of the North region therefore receives greater ecosystem services** from avoided runoff, carbon storage and sequestration, and air pollution removal.

The Centre region had the lowest species richness, species diversity, and percentage of trees which were native. The North region had the most tree species and proportion of trees public ownership, as well as coming second to the South East, for the highest tree diversity and percentage of trees which were native.

Table 13. Headline figures for Derby's Regions.

	Centre	North	South East	South West
Estimated total tree number	1,140	117,200	66,260	71,230
Tree per Ha	10.4	37.2	29.9	30.6
Canopy cover %	15.0	16.7	12.0	15.6
Leaf area (estimated Ha)	0.2	4.1	3.0	2.9
Three most common tree species	Rowan, Lime spp., Common apple	Leyland cypress, Sycamore, English oak	Black poplar, Common ash, Common Hawthorn	Sycamore, Leyland cypress, Silver birch
Number of tree species	4	41	29	28
Tree species diversity (SW index)	1.24	3.04	3.06	2.86
% of trees which are native	38	42	57	40
Tree public ownership %	25	31	21	24
Three most tree abundant land uses	Commercial/ Industrial, Institutional, Park	Residential, Park, Institutional	Residential, Golf course, Park	Residential, Institutional, Park
% of trees by size class (in cm)	7-20: 25 20-40: 50 40-60: 25 >60: (none)	7-20: 43.5 20-40: 34.4 40-60: 10.5 >60: 11.5	7-20: 47.8 20-40: 33 40-60: 10.4 >60: 8.7	7-20: 44.4 20-40: 38.7 40-60: 10.5 >60: 6.5
Avoided runoff (and value)	250 m^3 (£246) per year	39,848 m^3 (£39,178) per year	19,915 m^3 (£19,580) per year	19,911 m^3 (£19,577) per year

Air pollution removal (and value)	<1 tonne (£1,100) per year	30 tonnes (£142,200) per year	15 tonnes (£65,700) per year	15 tonnes (£69,300) per year
Carbon storage (and value)	456 tonnes (£409,488)	51,826 tonnes (£46,206,141)	25,442 tonnes (£22,847,006)	29,473 tonnes (£26,466,754)
Carbon sequestration (and value)	25 tonnes (£22,217) per year	1,443 tonnes (£1,286,744) per year	863 tonnes (£774,767) per year	913 tonnes (£819,856) per year
Amenity values (CAVAT)	£681	£889,422	£689,609	£303,549

Derby's wards

The per electoral ward data on Derby's urban forest is presented in Appendix IV. Table A4 displays the dominant land use, ground cover, and plantable space for each ward. Table A5 shows canopy cover for each Derby ward; the canopy cover across the 17 urban wards is 15.0%, this mean value is slightly higher than the 13.3% mean of the nine rural wards adjacent to Derby. Derby wards' tree composition is presented in Table A6, their species lists in Table A7, and the amount of ash they contain in Table A8.

Conclusions

Derby's urban forest is estimated to contain over **250 thousand trees**. A total of 61 species were identified in the survey[1]. The three most common tree species are Leyland cypress (x *Cupressocyparis* sp.), sycamore (*Acer pseudoplatanus*), then silver birch (*Betula pendula*). When considering tree abundance and leaf area sycamore is the most important. The most abundant, and important, genus is maple (*Acer* spp.).

Derby's urban forest provides **services valued at £3.26 million per annum**. This valuation only considers ecosystem services of air pollution removal, avoided stormwater runoff and carbon storage/sequestration, and does not include, for example, benefits to local temperature regulation, social and cultural values, and biodiversity support. These services can help Derby towards its goals of reducing greenhouse gas emissions and improving the health of its residents, by improving air quality and mitigating the risk of damage from flooding from stormwater runoff.

Derby's **canopy cover** was estimated as **8%[2].** Derby achieves 216th out of the 341 urban locations in rank descending order of canopy cover on the UK webmap[4]. This score is rather low, considering the list contains 'coastal' areas which tend to have lower canopy cover (Doick, *et al.*, 2017).

Derby's forest structure is **relatively balanced across taxa**, except an **overabundance of Leyland cypress**. There is no family which accounts for more than 30% of trees, and no genus accounting for a greater than 20% share. A single species, Leyland cypress, is in excess of recommendations (Santamour 1990) representing 12% of trees, and being the second most common shrub. This may limit the delivery of ecosystem services like biodiversity support, and the resilience of the urban forest to future pressures from climate change and emerging diseases.

1. 61 species, the comparable figure to previous studies is 80 (the number of unique entries which includes unknown species).
2. Calculated from i-Tree Eco.

Derby’s tree population is **quite balanced across size classes**, except **under-representation at DBH 40-60 cm**. 9% of Derby’s trees are estimated to be over 60 cm in DBH. Generally, the relative amount of trees which are in the <40 cm DBH, or the >60 cm DBH, size classes approximate recommendations (Richards 1983). However, medium-large diameters are only half of the 20% recommendation. Under-representation in the second largest DBH class is true for small and large stature trees; therefore, in the medium-term there may be a shortage of recruitment into girthy mature stands, which provide the greatest ecosystem service value.

The two most **important genera** in Derby, combining tree abundance and leaf area, were **maples and limes**. In Derby, maples were the most abundant genus, and correspondingly ranked high on ecosystem service delivery; for example, being nearly a third of the total CAVAT amenity value provided by urban trees. Limes are only the ninth most common genus in Derby, but are important because of their stature and maturity. They should be preserved as they are leaders in ecosystem service provision. For instance, limes contribute to a sixth of rainfall interception by trees, and hold a fifth of the carbon stored in the urban forest.

The **most abundant tree species** in Derby are **not necessarily the best** for **habitat provision**. For example, sycamore are the most abundant species (7.2% of the total community) support 43 insect species, whereas blackthorn, (0.7% of the total) supports 153 insect species. One of the three of the most common tree genera scores low for nectar/pollen and another for seeds/fruits.

16% of Derby’s urban forest had **excellent crown condition**, while **8% were in poor**, or worse, condition. Derby’s crown condition scores tended to be slightly lower than other i-Tree Eco studies.

Asian longhorn beetle, **Chalara ash dieback** and **Ramorum disease** were identified as the most concerning diseases for Derby’s urban forest. The assessment was for a dozen major existing or emerging tree diseases. Although not yet present in the UK, the Asian longhorn beetle had the highest theoretical CAVAT cost to replacement host trees. Chalara and Ramorum had the highest risk when considering the proportion of Derby’s tree community which could be affected, and their current establishment around the local area.

Chalara ash dieback could affect **6.6% of Derby’s trees**, with a CAVAT cost of **£43.3 million**. The amount of ash is relatively low compared to other i-Tree Eco studies. The region at greatest risk of Chalara was South East. The ward which could be most susceptible was Alvaston.

The **North** region of the study area holds **46%** of Derby's trees and has the greatest canopy cover **(16.7%).** Most of these trees were found in Residential and Park landscapes.

The **Central** region receives approximately **0.6%** of the annual **benefits** provided by Derby's urban forest, despite composing **1.4%** of the study **area**. This could mean residents in the Central region are less likely to benefit from the ecosystem services provided by trees. The other three regions all receive a greater proportion of annual benefit relative to their percentage area of Derby as a whole (North: 40%-46%, South West: 27%-30%, South East: 26%-28%). This may be particularly significant due to some of the greater concerns from residents in the Central region over their health.

The most common tree species in **public** ownership were European **alder (9.9%)** and Common **hawthorn (9.1%).** The high percentage of trees in private ownership (68.9%, which included Leyland cypress (17.5%), and Silver birch ((9.5%)) highlights the role of private tree owners in delivering ecosystem service benefits to the residents of Derby. This can represent a risk to the urban forest as there is less control over tree planting and management. However, this can also be an opportunity in educating land and homeowners of the benefits of tree planting, species selection and maintenance to better contribute to the sustainability of Derby's urban forest and the benefits it provides.

Recommendations

This section provides information on how Derby CC may improve its urban forest and increase its benefit provision to Derby's citizens.

Ownership and distribution

Most of Derby's trees are found on private land uses such as residential areas. This means that ecosystem services are centred on private land, which poses considerable risk with respect to the management and value of the urban forest. Enhancing and reviewing Tree Preservation Orders based on this report and Educating Derby's residents on the significance and needs of this important resource, can be a way to mitigate this risk. Engagement in stewardship may appeal to those interested in working as a community of good practice. To provide examples, in Sidmouth a civic arboretum has been formed through public action (Frediani, 2015), tree adoption/sponsorship schemes exist like TreeBristol, and nationally there are disease reporting systems like TreeAlert (Forest Research 2022b). It may be beneficial for Derby CC to undertake a detailed evaluation of local land use, enhancing this report's analysis of the proportional representation of trees on different land uses.

The distribution of tree cover across Derby's regions is not equal, for example the Northern region has a higher tree density. This may aid the health and wellbeing of residents in this region, whilst the converse may be true of lower tree density regions. For example, exposure to the natural environment was shown to reduce stress and improve memory in Stoke-on-Trent and Newcastle-under-Lyme (Lega et al. 2021). Additionally, across space and time in the UK, residential greenness has been shown to be associated with lower rates of major depressive disorders , and improved scores on mental health surveys (Alcock et al. 2014). Greening can be applied to new build developments, where the Woodland Trust suggests local authorities plan for a minimum of 30% canopy cover for new development land (Reid et al. 2021). A GIS based planting assessment, combined with socio-economic data from sources like the ONS may help identify where there is greatest opportunity expand canopy cover in the areas of most need.

Tree origin

The origin of tree species impacts on their ability to resist emerging pests and diseases like Chalara ash dieback, and climate change stresses such as prolonged exposure to drought and flood (Murphy et al., 2009). These factors are leading some councils to consider further use of exotic species. Exotic species tend to be competitive because enemy release; they are largely free from attack by native pests (Connor et al., 1980). Trees from warmer climates may also be able to better withstand the effects of climate change. Conversely, exotic species may support less native biodiversity and increase competition with native plants (Begon, Townsend, and Harper 2006). A balance of native and non-native species may provide the most resilient solution. In Derby's case, the two most common single species are Leyland cypress and sycamore, which are both non-native to the UK. Sycamore is known to have a high biodiversity value, whilst this is not the case for Leyland cypress, therefore it may be prudent in future to tend away from planting Leyland cypress and encourage planting of native species (O'Sullivan et al. 2017). Forest Research and the Royal Horticultural Society provide guidance on pest and drought adaptive tree selection (e.g., RHS, 2018b).

Size demography

Derby generally has a good ratio of large to small trees. However different land uses have very different DBH profiles. For example, golf courses and cemeteries are skewed towards large old trees. Whilst large trees are generally good for ecosystem service provision they need to be replaced by younger trees as they eventually die. Other land uses such as commercial/industrial and transportation have very few large trees, this may be a consequence of newly developed areas and/or management plans. Whichever, the planting of fast growing and large statured trees could be encouraged and protected in these areas. Furthermore, per region, the north has the highest proportion of large trees, whilst no trees >60cm DBH were sampled in the central region. In addition to the pollution, carbon and runoff reduction value of large trees, recent research suggests they may also have an impact on wellbeing (Wolf et al. 2020).

Crown condition and disease risk

Derby shows relatively few dead trees overall. However, further inquiry could be made as to why two species, silver birch and common hawthorn, have a relatively higher abundance of dead and poor condition trees. Moreover, particularly for the Northern region, ash trees have a very high proportion of poor and critical trees, which may be related to an outbreak of Chalara, though further investigation is needed. Derby's trees tend to be less healthy than previous i-Tree Eco studies, which may warrant further investigation. Chalara, Ramorum and Asian longhorn beetles were identified as the greatest risks for Derby; Forest Research's pest and disease pages provide information on how to monitor, and limit, threats.

Tree mortality impacts on ecosystem service provision, such as contributing towards losses to the urban tree carbon stock (-0.09 Tonnes of Carbon per hectare per year), and thereby reducing net carbon sequestration over time (0.41 Tonnes of Carbon per hectare per year). Previous research has shown urban street trees to have a net negative carbon balance (-0.15 Tonnes of Carbon per hectare per year), and thus the carbon stock of those trees will lose carbon over time (Smith, Dearborn, and Hutyra 2019). Planting initiatives alone may not be sufficient to maintain or enhance canopy cover and biomass due to the unique demographics of urban ecosystems. Initiatives to aid in the establishment and preservation of tree health are central for increasing street tree canopy cover and maintaining/increasing carbon storage in vegetation (Smith, Dearborn, and Hutyra 2019).

Habitat provision

Of the tree species considered, the most abundant taxa in Derby are not necessarily the best for supporting insects. For example, in Derby, sycamore is seven times more abundant than blackthorn, but theoretically sycamore only supports approximately a third of the species. To improve habitat provision to insects, one may consider in future increases the number of trees for groups like willows and oaks instead of sycamores and cypress. Two of the three most common tree genera in Derby rank relatively high in the provision of nectar/pollen (maples and plums/cherries) and seeds/fruits (plums/cherries and oaks). Increasing the proportion of hawthorns, willows, whitebeams, alders, and limes may improve food provision. Note that the cherry/plum, whitebeam, and hawthorn groups perform well as supplying nectar/pollen as well as seeds/fruit. Increasing their abundance may be a particularly effective use of space, supporting diverse feeding guilds and supply food across seasons.

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Acknowledgements

We thank: Derby CC for funding this project; FR's Fineshade Technical Service Unit (TSU), including Jeremy Splude and Liz Richardson, as well as Derby volunteers, especially Josie Jackson and Reg Hand, for conducting the field work; The Woodland Trust and CEH (Centre for Hydrology and Ecology) for access to the UK Phenology Network required in the creation of i-Tree Eco v 6.0; as well as The USDA Forest Service, and the i-Tree Cooperative (page 10) for their on-going support.

Thank you to all the landowners and members of the public in Derby who allowed access to their properties for the collection of field data.

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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 et al. 2008), including:

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

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

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

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

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

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

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

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

The Standard volumetric rate – Surface water rebated per cubic metre value of £0.98 of waste water to public sewer, set by the Severn Trent sewerage cost for the East Midlands in 2021/2 was used as a representative value of the avoided cost of treating surface water runoff across the whole survey area.

Calculating current carbon storage: biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak 1995). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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

Calculating air pollution removal: estimates are derived from calculated hourly tree-canopy resistances for ozone and sulphur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988; Baldocchi, Hicks, and Camara 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 USA CTLA approach (CTLA, 1992), which uses tree species, diameter, condition and location information. In this case values are calculated using standard i-Tree inputs such as per cent canopy missing.

Tree condition: is reported following Nowak et al. (2008) wherein trees are assigned to one of seven classes according to percentage dieback in the crown area:

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

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

US Externality and UK Social Damage Costs

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

Official pollution values for the UK are however based on the estimated social cost of the pollutant in terms of impact upon human health, damage to buildings and crops. This approach is termed ‘the costs approach’. Values were taken from (DEFRA 2010) which are based on the Interdepartmental Group on Costs and Benefits (IGCB). There are three levels of ‘sensitivity’ applied to the air pollution damage cost approach: ‘High’, ‘Central’ and ‘Low’. This report uses the ‘Central’ scenario based on 2010 prices.

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

The key effects that have not been included are:

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

CAVAT Analysis

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

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

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

The CTI rating was constant across Derby at 125%. 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

Table A3. Importance values from i-Tree for all species encountered during the study (see Section 'Leaf Area' in the Urban Forest Structure sub-chapter).

Species	Percent Population	Percent Leaf Area	Importance Value
Sycamore	7.20	11.70	18.80
Lime spp	3.70	15.10	18.80
Leyland cypress	12.10	3.80	15.90
Common ash	4.20	8.00	12.20
Black poplar	2.50	8.90	11.30
Silver birch	6.40	2.70	9.20
English oak	4.00	4.70	8.70
Hedge maple	2.40	5.60	8.00
European alder	3.60	2.90	6.40
Common hawthorn	4.00	1.90	5.90
European bird cherry	3.10	1.60	4.70
Rowan	3.70	0.60	4.30
Black locust	2.70	1.50	4.20
Ash spp	2.20	1.70	3.90
Crack willow	2.00	1.90	3.90
Norway maple	1.30	2.20	3.60
Sweet cherry	2.40	0.90	3.40
English yew	1.30	1.60	3.00
Common beech	1.30	1.60	2.90
Maple spp	1.60	1.30	2.90
Hawthorn spp	1.80	1.00	2.80
Holly spp	2.00	0.60	2.50
Black cottonwood	0.20	2.20	2.50
Apple spp	2.00	0.40	2.30
Cypress spp	1.60	0.50	2.10
Horse chestnut	0.70	1.30	2.10
Norway spruce	0.70	1.40	2.00
Italian alder	0.40	1.40	1.80
Atlas cedar	0.50	1.30	1.80
White willow	0.40	1.00	1.50

Birch spp	0.70	0.80	1.50
Plum spp	1.30	0.00	1.40
Callery pear	0.70	0.40	1.10
False cypress spp	0.90	0.20	1.00
Common plum	0.90	0.20	1.00
Hazelnut spp	0.20	0.80	1.00
Cherry plum	0.40	0.40	0.90
Lawson’s cypress	0.70	0.20	0.80
Oak spp	0.20	0.60	0.80
Lombardy poplar	0.20	0.60	0.80
Hornbeam spp	0.50	0.30	0.80
Cherry laurel	0.20	0.50	0.70
Blackthorn	0.70	0.10	0.70
Holly oak	0.20	0.50	0.70
Elm spp	0.40	0.20	0.60
Whitebeam	0.20	0.40	0.60
Sweet chestnut	0.50	0.20	0.60
Golden chain tree	0.40	0.20	0.60
Yew spp	0.20	0.30	0.50
English holly	0.40	0.10	0.50
Common apple	0.50	0.00	0.50
Crabapple	0.40	0.10	0.50
Wych elm	0.40	0.10	0.50
Elder	0.40	0.00	0.50
Monkeypuzzle tree	0.20	0.20	0.50
Windmill palm	0.40	0.00	0.40
White ash	0.20	0.20	0.40
Indian paper birch	0.20	0.20	0.40
Goat willow	0.20	0.10	0.40
Scots pine	0.20	0.10	0.30
Pear spp	0.20	0.10	0.30
Pine spp	0.20	0.10	0.30
Swedish Whitebeam	0.20	0.10	0.30
English elm	0.20	0.10	0.30
Arbol de judea	0.20	0.00	0.30
Crabapple John Downie	0.20	0.00	0.30
Magnolia spp	0.20	0.00	0.30

Rowan spp	0.20	0.00	0.30
Glossy buckthorn	0.20	0.00	0.30
Serviceberry spp	0.20	0.00	0.20
Southern catalpa	0.20	0.00	0.20
Red snakebark maple	0.20	0.00	0.20
Witchhazel spp	0.20	0.00	0.20
European crabapple	0.20	0.00	0.20
Sweetgum	0.20	0.00	0.20
Japanese maple	0.20	0.00	0.20
European hornbeam	0.20	0.00	0.20
Fig tree	0.20	0.00	0.20
Purpleleaf sand cherry	0.20	0.00	0.20
Golden-chain tree	0.20	0.00	0.20
Needle palm	0.20	0.00	0.20

Appendix III – Pests and Diseases

Acute Oak Decline

Acute oak decline (AOD) affects mature trees (>50 years old) of both native oak species (common oak and sessile oak), and can kill within four to six years. Over the past six years, the reported incidents of stem bleeding, a potential symptom of AOD, have been increasing. The condition seems to be most prevalent in the South East of England, being exacerbated by drought and air pollution. Its range extends up past derby, stopping short of the Humber. Predictive modelling which considers temperature, rainfall and nitrogen air pollution suggest Derby is an intermediate to moderately high risk of AOD establishing (Forest Research 2022a).

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.

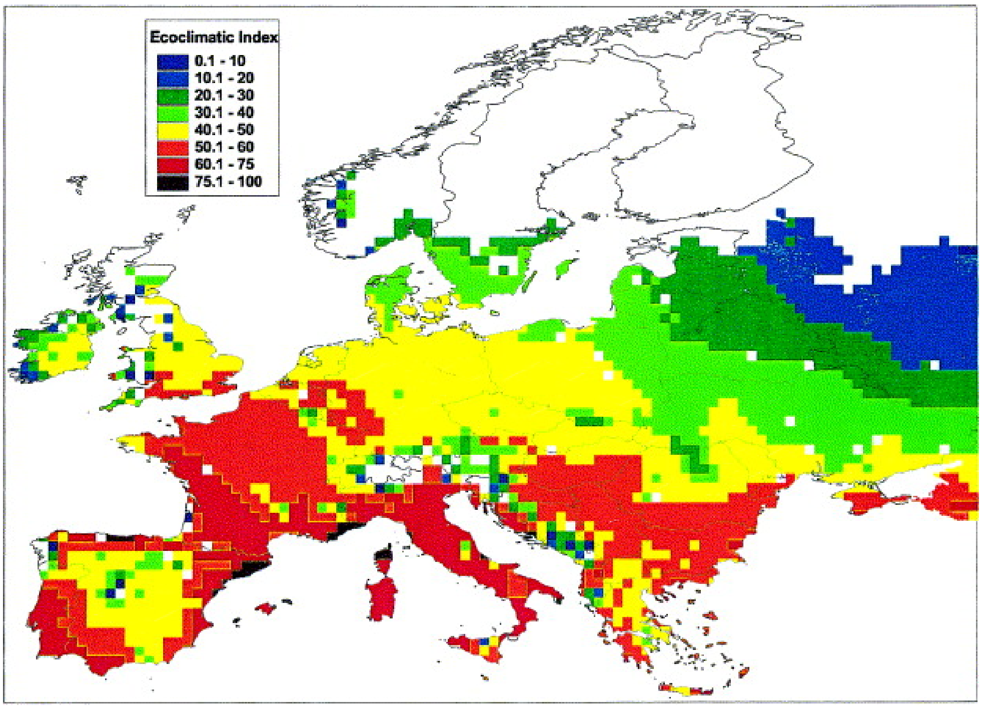

Figure A. Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB (MacLeod *et al.,* 2002).

In March 2012 an ALB outbreak was found in Maidstone, Kent originating from untreated wooden pallets. The Forestry Commission and Fera removed more than 2,000 trees from the area to contain the outbreak (Straw et al. 2016). No further outbreaks have been reported in the UK. MacLeod, Evans & Baker (2002) modelled climatic suitability for outbreaks based on outbreak data from China and the USA and suggested that CLIMEX (the model used) Ecoclimatic Indices of >32 could be suitable habitats for ALB. Figure A suggests that Derby may be vulnerable to ALB under this model.

Tree host species include:

Acer spp. (maples and sycamores)

Aesculus spp. (chestnuts)

Alnus spp. (alder)

Betula spp. (birch)

Carpinus spp. (hornbeam)

Corylus spp. (hazel)

Fagus spp. (beech)

Fraxinus spp. (ash)

Malus domestica (apple)

Platanus spp. (plane)

Populus spp. (poplar)

Pyrus spp. (pear)

Prunus spp. (cherry, plum)

Salix spp. (willow, sallow)

Sorbus spp. (rowan, whitebeam etc)

Tilia spp. (lime)

Quercus rubra (red oak)

Ulmus spp. (elm)

Chalara Dieback of Ash

Please see the Chalara Ash dieback section.

Two lined chestnut borer

The beetle is native to middle and eastern North America, and established in Turkey in 2002. There is no evidence to date that emerald ash borer (EAB) is present in the UK, however imported oak and chestnut products are a significant risk for its accidental introduction. Its primary hosts are oaks, and the American sweet chestnut however, it is thought to be likely that it could jump to the European sweet chestnut. It seems to be a secondary pest, primarily infecting weakened trees, a scenario which is likely considering the number of diseases established on oaks in the UK, such as AOD, SOD and OPM.

Bronze birch borer

The beetle burrows into the trunk of birch species, leading to leaf yellowing, crown dieback, sap ooze, emergence holes, and if the infection is severe, death from girdling. It is native to southern North America, with no evidence that it is present in the UK. It seems to be a secondary pest, primarily infecting weakened trees.

Emerald Ash Borer

There is no evidence to date that emerald ash borer (EAB) beetle 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. However, it can very damaging, in the USA costs from damage and management are estimated to be up to $300 billion (Poland and McCullough 2006). EAB is present in Russia and is moving West and South at a rate of 30-40 km per year, perhaps aided by vehicles (Straw et al. 2013). EAB has had a devastating effect in the USA due to its accidental introduction and could add to pressures already imposed on ash trees from diseases such as chalara dieback of ash.

Oak Processionary Moth

It was first accidentally introduced to Britain in 2005, and it is theoretically possible that if it were to spread it could survive and breed in much of England and Wales. Established breeding populations of oak processionary moth (OPM) have been found in South and South West London and in Berkshire. It is thought that OPM has been spread on nursery trees. The caterpillars cause serious defoliation of oak trees, their principal host, but the trees will recover and leaf the following year. On the continent, they have also been associated with hornbeam, hazel, beech, sweet chestnut, and birch, but usually only where there is heavy infestation of nearby oak trees. The caterpillars have urticating (irritating) hairs that carry a toxin that can be blown in the wind and cause serious irritation to the skin, eyes and bronchial tubes of humans and animals. They are considered a significant human health problem when populations reach outbreak proportions, such as those in The Netherlands and Belgium have done in recent years. The outbreak in London is beyond eradicating, however there are efforts to stop the spread out of London and minimise the impact. There have been no confirmed cases found in Wales to date.

Ramorum disease

Phytophthora ramorum, a species of water mould, was first found in the UK in 2002 and primarily affects North American species of oak (Turkey, red, holm oak), beech, sweet chestnut, and larch. It can also spread to other conifers outside larch. The disease has a variety of synonyms, including sudden oak death. Rhododendron is a major host, which aids the spread of the disease. The disease is concentrated along the wetter wide side of the UK, in England this is especially the North and South West. There are reports over the past decade in the Stoke-on-Trent area (Forest Research 2020).

Tree host species include:

Acer spp. (maples and sycamores)	*Castanea sativa* (sweet chestnut)
Aesculus hippocastanum (horse chestnut)	*Fagus* spp. (beech)
Alnus spp. (alder)	*Fraxinus excelsior* (common ash)
Betula pendula (silver birch)	*Hamamelis* (witchhazel)

Ilex spp. (holly)

Larix spp. (larch)

Laurus nobilis (bay laurel)

Magnolia spp. (magnolia)

Prunus laurocerasus (cherry laurel)

Rhododendron spp. (rhododendron)

Quercus cerris (Turkey oak)

Q. ilex (holm oak)

Q. rubra (red oak)

Salix caprea (goat willow)

Taxus baccata (English yew)

Alder bleeding canker

Phytophthora alni, a species of water mould, was first discovered in the UK in 1993, it is widespread with high concentrations in the southeast and long the borders of Wales and Scotland. It is associated with riparian ecosystems, its incidence increases with distance to the river bank, and with the size of the river. Heavy losses are occurring in some of the large alder populations that occur in the West, such as the Welsh Marches. Derby may be at risk, considering the Derwent and Trent rivers.

Phytophthora kernoviae

Phytophthora kernoviae, a species of water mould, was first discovered in Cornwall in 2003, and has spread to at least to the south east and north west. Its symptoms include leaf browning, lethal stem cankers and necrosis of the inner bark. The disease primarily infects rhododendron and bilberry (*Vaccinium*), but to a lesser extent, a range of other trees. It can also target ornamental plants like magnolia and camellia.

Tree host species include:

Aesculus hippocastanum (horse chestnut)

Castanea sativa (sweet chestnut)

Fagus sylvatica (common beech)

Ilex aquifolium (European holly)

Magnolia spp. (magnolia)

Rhododendron spp. (rhododendron)

Quercus ilex (holm oak)

Q. robur (English oak)

Xylella fastidiosa

X. fastidiosa is a bacterium which infects vascular systems, restricting the movement of water and nutrients. Symptoms include stunting, leaf scorch and dieback. It is present in the wider environment in France, Spain, Italy, the Americas, and Taiwan, however, it has not arrived in the UK yet despite the interception of an infected imported plant. X. *fastidiosa* sub-species *multiplex* perhaps has the greatest potential range of hosts in the UK, including English oak, wych elm, plane, and northern red oak.

Tree host species include:

Acer pseudoplatanus (sycamores)

Ficus carica (fig)

Fraxinus angustifolia (narrow-leaved ash)

Laurus nobilis (bay laurel)

Magnolia spp. (magnolia)

Prunus spp. (cherry, plum)

Ligustrum (privet)

Rhododendron spp. (rhododendron)

Quercus cerris (Turkey oak)

Quercus robur (English oak)

Q. rubra (red oak)

Ulmus glabra (wych elm)

Salix caprea (goat willow)

Appendix IV – Ward-specific Results

Table A3. Derby plot sample sizes by electoral ward and region.

Region		Ward	
Name	Plot count	Name	Plot count
Central	20	Arboretum	20
North	143	Allestree	29
		Chaddesden	15
		Darley	23
		Derwent	22
		Oakwood	16
		Spondon	38
South East	99	Alvaston	29
		Boulton	14
		Chellaston	25
		Sinfin	31
South West	104	Abbey	14
		Arboretum	11
		Blagreaves	16
		Littleover	24
		Mackworth	10
		Mickleover	22
		Normanton	7

Table A4. Ward-specific comparisons of headline land use statistics.

Ward	Top land use	Prevalence of top land use	Top ground cover	Prevalence of top ground cover	% of plot which is plantable	% of trees on public land uses
Abbey	Residential	50%	Tar	24%	7%	0%
Allestree	Residential	44%	Grass	58%	42%	49%
Alvaston	Residential	41%	Grass	32%	24%	17%
Arboretum	Commercial/ Industrial	56%	Cement	46%	10%	76%
Blagreaves	Residential	72%	Grass	32%	28%	0%
Boulton	Residential	50%	Grass	44%	14%	9%
Chaddesden	Residential	36%	Grass	50%	26%	0%
Chellaston	Residential	35%	Grass	51%	32%	45%
Darley	Institutional	25%	Building	26%	26%	7%
Derwent	Residential	36%	Grass	38%	15%	65%
Littleover	Residential	42%	Cement	21%	41%	3%
Mackworth	Residential	60%	Cement	51%	10%	0%
Mickleover	Residential	67%	Grass	25%	25%	65%
Normanton	Residential	58%	Cement	40%	3%	0%
Oakwood	Residential	75%	Building	31%	8%	26%
Sinfin	Residential	41%	Building	34%	12%	20%
Spondon	Commercial/ Industrial	37%	Cement	40%	26%	12%

Table A5. Region- and ward-specific canopy covers from the i-Tree canopy webmap assessment. Canopy covers defined as the mean percentage of land surface covered by tree canopy.

Name	Average Canopy Cover %	Standard Error
Arboretum	15.2	2.0
Allestree	26.2	2.0
Chaddesden	2.7	1.9
Darley	18.0	2.0
Derwent	14.0	2.0
Oakwood	15.4	2.0
Spondon	17.0	2.0
Alvaston	12.3	1.9
Boulton	9.3	1.7
Chellaston	12.3	1.9
Sinfin	12.7	1.9
Abbey	19.9	2.0
Blagreaves	16.3	2.0
Littleover	18.5	2.0
Mackworth	11.0	1.9
Mickleover	15.0	2.1
Normanton	10.0	1.7

Table A6. Ward-specific comparisons of Headline tree population figures.

Ward	Land use with the most trees	Estimated number of trees	Relative proportion of total trees	Number of species	Mean DBH (cm)	Mean tree height (m)
Abbey	Institutional	12,287	4%	7	28	11
Allestree	Park	65,667	16%	26	29	13
Alvaston	Commercial /Industrial	29,962	6%	15	17	9
Arboretum	Vacant	7,784	5%	9	31	12
Blagreaves	Residential	5,593	1%	4	25	9
Boulton	Residential	11,000	2%	7	35	11
Chaddesden	Residential	11,500	3%	9	23	9
Chellaston	Park	30,352	7%	17	23	7
Darley	Residential	45,085	9%	16	25	9
Derwent	Residential	38,484	7%	12	29	11
Littleover	Residential	44,492	9%	17	26	10
Mackworth	Residential	2,861	<1%	2	45	6
Mickleover	Transportation	42,106	10%	15	25	11
Normanton	Residential	945	<1%	1	31	15
Oakwood	Residential	20,520	5%	15	32	11
Sinfin	Golf course	45,469	10%	23	36	18
Spondon	Residential	26,218	5%	17	32	9

Table A7. Ward-specific comparisons of Headline tree population figures.

Ward	Scientific Name	Family	Common name	Relative abundance of each species per ward
Abbey	*x Cupressocyparis leylandii*	Cupressaceae	Leyland cypress	6%
	Tilia	Tiliaceae	Lime spp	12%
	Betula pendula	Betulaceae	Silver birch	59%
	Acer pseudoplatanus	Aceraceae	Sycamore	6%
	Cupressus	Cupressaceae	Cypress spp	6%
	Sorbus aucuparia	Rosaceae	Rowan	6%
Abbey	*Salix caprea*	Salicaceae	Goat willow	6%
Allestree	*Quercus ilex*	Fagaceae	Holm oak	1%
	Acer pseudoplatanus	Aceraceae	Sycamore	8%
	Betula	Betulaceae	Birch spp	3%
	Quercus robur	Fagaceae	English oak	1%
	Crataegus	Rosaceae	Hawthorn spp	1%
	Fraxinus	Oleaceae	Ash spp	12%
	Ulmus	Ulmaceae	Elm spp	3%
	Alnus glutinosa	Betulaceae	European alder	8%
	Prunus avium	Rosaceae	Sweet cherry	1%
	Fagus sylvatica	Fagaceae	Common beech	1%
	x Cupressocyparis leylandii	Cupressaceae	Leyland cypress	22%
	Sorbus aucuparia	Rosaceae	Rowan	1%
	Malus	Rosaceae	Apple spp	4%
	Ilex	Aquifoliaceae	Holly spp	3%
	Frangula alnus	Rhamnaceae	Glossy buckthorn	1%
	Fraxinus excelsior	Oleaceae	Common ash	1%
	Aesculus hippocastanum	Hippocastanaceae	Horse chestnut	1%
	Prunus padus	Rosaceae	European bird cherry	1%
	Prunus spinosa	Rosaceae	Blackthorn	4%

Allestree	*Crataegus monogyna*	Rosaceae	Common Hawthorn	1%
	Taxus baccata	Taxaceae	English yew	5%
	Acer campestre	Aceraceae	Field maple	5%
	Ilex aquifolium	Aquifoliaceae	Common holly	1%
	Taxus	Taxaceae	Yew spp	1%
	Betula pendula	Betulaceae	Silver birch	3%
	Catalpa bignonioides	Bignoniaceae	Southern catalpa	1%
Alvaston	*Betula pendula*	Betulaceae	Silver birch	3%
	Fraxinus excelsior	Oleaceae	Common ash	24%
	Tilia	Tiliaceae	Lime spp	3%
	Robinia pseudoacacia	Fabaceae	Black locust	3%
	Alnus glutinosa	Betulaceae	European alder	10%
	Salix fragilis	Salicaceae	Crack willow	3%
	Pinus	Pinaceae	Pine spp	3%
	Prunus padus	Rosaceae	European bird cherry	7%
	Crataegus monogyna	Rosaceae	Common Hawthorn	3%
	Prunus avium	Rosaceae	Sweet cherry	10%
	Sorbus	Rosaceae	Mountain ash spp	3%
	Amelanchier	Rosaceae	Serviceberry spp	3%
	Betula	Betulaceae	Birch spp	3%
	Carpinus betulus	Betulaceae	European hornbeam	3%
Alvaston	*x Cupressocyparis leylandii*	Cupressaceae	Leyland cypress	14%
Arboretum	*Malus domestica*	Rosaceae	Common apple	5%
	Acer pseudoplatanus	Aceraceae	Sycamore	5%
	Aesculus hippocastanum	Hippocastanaceae	Horse chestnut	5%
	Sorbus aucuparia	Rosaceae	Rowan	19%
	Tilia	Tiliaceae	Lime spp	24%
	Sambucus nigra	Caprifoliaceae	Elder	5%
	Liquidambar styraciflua	Hamamelidaceae	Sweetgum	5%

Arboretum	*Alnus glutinosa*	Betulaceae	European alder	29%
Arboretum	*Castanea sativa*	Fagaceae	Sweet chestnut	5%
Blagreaves	*Prunus cerasifera*	Rosaceae	Cherry plum	17%
	Prunus padus	Rosaceae	European bird cherry	33%
	Acer pseudoplatanus	Aceraceae	Sycamore	33%
Blagreaves	*Sorbus aucuparia*	Rosaceae	Rowan	17%
Boulton	*Tilia*	Tiliaceae	Lime spp	36%
	Prunus padus	Rosaceae	European bird cherry	9%
	Sorbus aucuparia	Rosaceae	Rowan	9%
	Betula utilis	Betulaceae	Indian paper birch	9%
	Macromeles tschonoskii	Rosaceae	Crabapple	9%
	Acer platanoides	Aceraceae	Norway maple	18%
Boulton	*Cercis siliquastrum*	Fabaceae	Arbol de judea	9%
Chaddesden	*Rhapidophyllum hystrix*	Arecaceae	Needle palm	8%
	Sorbus aucuparia	Rosaceae	Rowan	8%
	Salix fragilis	Salicaceae	Crack willow	8%
	Quercus robur	Fagaceae	English oak	23%
	Acer pseudoplatanus	Aceraceae	Sycamore	23%
	Robinia pseudoacacia	Fabaceae	Black locust	8%
	Chamaecyparis	Cupressaceae	False cypress spp	8%
	Malus	Rosaceae	Apple spp	8%
Chaddesden	*Tilia*	Tiliaceae	Lime spp	8%
Chellaston	*Crataegus*	Rosaceae	Hawthorn spp	10%
	Crataegus monogyna	Rosaceae	Common Hawthorn	23%
	Fraxinus excelsior	Oleaceae	Common ash	3%
	Ilex	Aquifoliaceae	Holly spp	3%
	Cupressus	Cupressaceae	Cypress spp	3%
	Betula pendula	Betulaceae	Silver birch	10%
	Ficus vasta	Moraceae	Fig tree	3%

	Chamaecyparis	Cupressaceae	False cypress spp	3%
	Trachycarpus fortunei	Arecaceae	Windmill palm	3%
	Sorbus aucuparia	Rosaceae	Rowan	6%
	Prunus avium	Rosaceae	Sweet cherry	3%
	Tilia	Tiliaceae	Lime spp	3%
	Ulmus glabra	Ulmaceae	Wych elm	6%
	Magnolia	Magnoliaceae	Magnolia spp	3%
	Acer pseudoplatanus	Aceraceae	Sycamore	10%
	Sambucus nigra	Caprifoliaceae	Elder	3%
Chellaston	*Chamaecyparis lawsoniana*	Cupressaceae	Lawson's cypress	3%
Darley	*Acer pseudoplatanus*	Aceraceae	Sycamore	12%
	Alnus cordata	Betulaceae	Italian alder	2%
	Sorbus aucuparia	Rosaceae	Rowan	7%
	x Cupressocyparis leylandii	Cupressaceae	Leyland cypress	29%
	Ilex	Aquifoliaceae	Holly spp	7%
	Fagus sylvatica	Fagaceae	Common beech	2%
	Prunus avium	Rosaceae	Sweet cherry	5%
	Acer	Aceraceae	Maple spp	2%
	Taxus baccata	Taxaceae	English yew	2%
	Acer palmatum	Aceraceae	Japanese maple	2%
	Pyrus calleryana	Rosaceae	Callery pear	5%
	Acer campestre	Aceraceae	Field maple	2%
	Prunus	Rosaceae	Cherry spp	14%
	Quercus	Fagaceae	Oak spp	2%
	Chamaecyparis	Cupressaceae	False cypress spp	2%
Darley	*Hamamelis*	Hamamelidaceae	Witchhazel spp	2%
Derwent	*Quercus robur*	Fagaceae	English oak	3%
	Betula pendula	Betulaceae	Silver birch	9%
	Crataegus monogyna	Rosaceae	Common Hawthorn	18%
	x Cupressocyparis leylandii	Cupressaceae	Leyland cypress	27%

Derwent	*Tilia*	Tiliaceae	Lime spp	3%
	Acer platanoides	Aceraceae	Norway maple	6%
	Fraxinus excelsior	Oleaceae	Common ash	9%
	Acer campestre	Aceraceae	Field maple	9%
	Malus sylvestris	Rosaceae	European crabapple	3%
	Laburnum x watereri	Fabaceae	Golden-chain tree	6%
	Pyrus	Rosaceae	Pear spp	3%
	Chamaecyparis lawsoniana	Cupressaceae	Lawson's cypress	3%
Littleover	*Crataegus*	Rosaceae	Hawthorn spp	3%
	Acer pseudoplatanus	Aceraceae	Sycamore	13%
	Fraxinus excelsior	Oleaceae	Common ash	10%
	Betula pendula	Betulaceae	Silver birch	3%
	Prunus padus	Rosaceae	European bird cherry	5%
	Crataegus monogyna	Rosaceae	Common Hawthorn	8%
	Cupressus	Cupressaceae	Cypress spp	8%
	Ilex	Aquifoliaceae	Holly spp	8%
	Taxus baccata	Taxaceae	English yew	3%
	Sorbus aria	Rosaceae	Whitebeam	3%
	x Cupressocyparis leylandii	Cupressaceae	Leyland cypress	18%
	Picea abies	Pinaceae	Norway spruce	5%
	Prunus domestica	Rosaceae	Common plum	3%
	Malus	Rosaceae	Apple spp	5%
	Pyrus calleryana	Rosaceae	Callery pear	3%
	Castanea sativa	Fagaceae	Sweet chestnut	3%
Littleover	*Acer capillipes*	Aceraceae	Red snakebark maple	3%
Mackworth	*Acer campestre*	Aceraceae	Field maple	50%
	Chamaecyparis lawsoniana	Cupressaceae	Lawson's cypress	50%
Mickleover	*Aesculus hippocastanum*	Hippocastanaceae	Horse chestnut	4%
	Quercus robur	Fagaceae	English oak	9%
	Carpinus	Betulaceae	Hornbeam spp	4%

	Crataegus	Rosaceae	Hawthorn spp	4%
	Pinus sylvestris	Pinaceae	Scots pine	2%
	Prunus padus	Rosaceae	European bird cherry	9%
	Sorbus aucuparia	Rosaceae	Rowan	7%
	x Cupressocyparis leylandii	Cupressaceae	Leyland cypress	9%
	Betula pendula	Betulaceae	Silver birch	2%
	Fraxinus americana	Oleaceae	White ash	2%
	Robinia pseudoacacia	Fabaceae	Black locust	22%
	Acer pseudoplatanus	Aceraceae	Sycamore	9%
	Acer	Aceraceae	Maple spp	11%
	Cedrus atlantica	Cupressaceae	Atlas cedar	4%
Mickleover	*Acer platanoides*	Aceraceae	Norway maple	2%
Normanton	*Acer pseudoplatanus*	Aceraceae	Sycamore	100%
Oakwood	*Populus nigra v. italica*	Salicaceae	Lombardy poplar	4%
	Quercus robur	Fagaceae	English oak	22%
	Betula pendula	Betulaceae	Silver birch	22%
	Salix fragilis	Salicaceae	Crack willow	4%
	Malus 'John Downie'	Rosaceae	Crabapple John Downie	4%
	Malus	Rosaceae	Apple spp	4%
	Picea abies	Pinaceae	Norway spruce	4%
	Prunus cerasifera	Rosaceae	Cherry plum	4%
	Prunus avium	Rosaceae	Sweet cherry	4%
	Laburnum anagyroides	Fabaceae	Golden chain tree	4%
	Prunus domestica	Rosaceae	Common plum	4%
	x Cupressocyparis leylandii	Cupressaceae	Leyland cypress	4%
	Trachycarpus fortunei	Arecaceae	Windmill palm	4%
	Fraxinus excelsior	Oleaceae	Common ash	4%
Oakwood	*Sorbus aucuparia*	Rosaceae	Rowan	4%
Sinfin	*Cupressus*	Cupressaceae	Cypress spp	4%
	Malus	Rosaceae	Apple spp	2%

	Fraxinus	Oleaceae	Ash spp	2%
	x Cupressocyparis leylandii	Cupressaceae	Leyland cypress	2%
	Crataegus	Rosaceae	Hawthorn spp	2%
	Acer pseudoplatanus	Aceraceae	Sycamore	4%
	Fagus sylvatica	Fagaceae	Common beech	9%
	Macromeles tschonoskii	Rosaceae	Crabapple	2%
	Acer	Aceraceae	Maple spp	2%
	Alnus cordata	Betulaceae	Italian alder	2%
	Fraxinus excelsior	Oleaceae	Common ash	4%
	Sorbus intermedia	Rosaceae	Swedish Whitebeam	2%
	Malus domestica	Rosaceae	Common apple	4%
	Betula pendula	Betulaceae	Silver birch	4%
	Corylus	Betulaceae	Hazelnut spp	2%
	Quercus robur	Fagaceae	English oak	4%
	Salix alba	Salicaceae	White willow	4%
	Alnus glutinosa	Betulaceae	European alder	2%
	Acer campestre	Aceraceae	Field maple	2%
	Salix fragilis	Salicaceae	Crack willow	7%
	Populus nigra	Salicaceae	Black poplar	24%
	Tilia	Tiliaceae	Lime spp	2%
Sinfin	*Acer platanoides*	Aceraceae	Norway maple	2%
Spondon	*Ulmus procera*	Ulmaceae	English elm	4%
	Prunus padus	Rosaceae	European bird cherry	8%
	Sorbus aucuparia	Rosaceae	Rowan	4%
	Malus	Rosaceae	Apple spp	4%
	Prunus domestica	Rosaceae	Common plum	8%
	Prunus avium	Rosaceae	Sweet cherry	12%
	Tilia	Tiliaceae	Lime spp	8%
	Populus trichocarpa	Salicaceae	Black cottonwood	4%
	Prunus laurocerasus	Rosaceae	Cherry laurel	4%
	Quercus robur	Fagaceae	English oak	8%
	Salix fragilis	Salicaceae	Crack willow	12%

Spondon	*Chamaecyparis*	Cupressaceae	False cypress spp	4%
	Araucaria araucana	Araucariaceae	Monkeypuzzle tree	4%
	Prunus x cistena	Rosaceae	Purpleleaf sand cherry	4%
	Ilex aquifolium	Aquifoliaceae	Common holly	4%
	Acer campestre	Aceraceae	Field maple	4%
	Betula pendula	Betulaceae	Silver birch	4%

Table A8. The percentage of each ward's tree community which is Ash (*Fraxinus* spp.), and therefore susceptible to Chalara.

Ward	Ash as % of tree population
Abbey	0
Allestree	14
Alvaston	24
Arboretum	0
Blagreaves	0
Boulton	0
Chaddesden	0
Chellaston	3
Darley	0
Derwent	9
Littleover	10
Mackworth	0
Mickleover	2
Normanton	0
Oakwood	4
Sinfin	7
Spondon	0

Appendix V - Glossary of Terms

Average / Mean – measure of central tendency, sum of values divided by their sample size.

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.

Champion trees – individual trees which are exceptional examples of their species because of their enormous size, great age, rarity, or historical significance.

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

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

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

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

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

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

Disease - a disorder or of normal structure or function, resulting in symptoms and reduced health, typically from continued disturbance from biological agents or environmental conditions.

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.

Median – measure of central tendency, the middle value where all values are sorted by size.

Meteorological - phenomena of the atmosphere or weather.

Native –species which have established in the UK ecosystem naturally over a long period, without human agency.

Naturalised – species which has (un)intentionally introduced to a new UK by humans, which has adapted to conditions and formed a sustained population.

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 – infectious biological agents capable of causing disease, typically microscopic such as: bacteria, viruses, protozoa, or fungi.

Pest – usually a term for herbivorous animals which cause damage to plant tissue, the majority of members are insects.

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

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

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

Standard error (SE) – measure of variation, the amount by which sample averages differ from one another, the standard deviation (data spread) divided by the square-root of the sample size.

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 (e.g., Oak Processionary Moth (*Thaumetopoea processionea*)). 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 (VOCs)- 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.

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