Valuing the urban trees of Chepstow and Severnside

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.

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.

This report should be cited as:
Sales, K., Chambers-Ostler, A., Walker, H., Handley, P., Sparrow, K., and Doick, K.J. (2022). Valuing the urban trees of Chepstow and Severnside. A report to Monmouthshire County Council. Forest Research, Farnham. pp 87.

A project for:

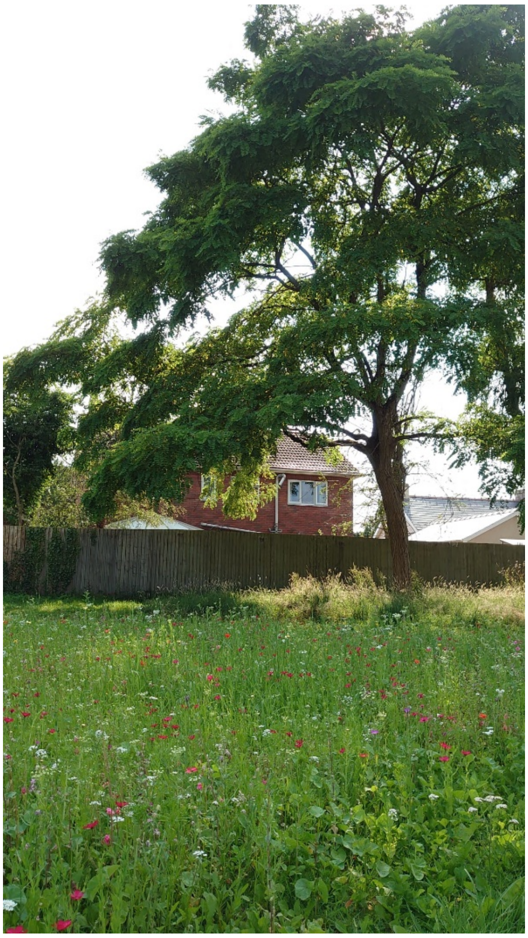
The Gwent Green Grid Partnership, with funding from the European Agricultural Fund for Rural Development: Europe Investing in Rural Areas.

Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig:
Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
European Agricultural Fund for Rural Development:
Europe Investing in Rural Areas

Llywodraeth Cymru
Welsh Government

CONTENTS

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 IV.

Executive Summary

Urban trees form a resource that has a range of positive effects on human populations living in and around them. 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, control water runoff and flooding, as well as cool and stabilise urban microclimates. 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.

To improve our understanding of the structure and service provision of Monmouthshire'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 Monmouthshire's urban forest resource. i-Tree Eco also allocates monetary values to some services such as carbon storage and pollution removal, therefore increasing the profile of Monmouthshire'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 the south **Monmouthshire (referred to as Monmouthshire throughout) study area's urban forest**, its **composition, condition, and public amenity value**. It shows that residents of, and visitors to, Monmouthshire benefit significantly from urban trees. In terms of avoided water runoff, carbon sequestration and the removal of three types of air pollutants, **The Monmouthshire study area's urban forest provides ecosystem services worth £757,300 per year**. Though this value is high, it is an **underestimate** because it omits many ecosystem services that i-Tree Eco cannot currently assess, including cooling local air temperatures and reducing noise pollution. This study represents the present and 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 Monmouthshire's urban forest should change in the future, and how to ensure its resilience to global change. The study was commissioned by Monmouthshire County Council (Monmouthshire CC) and delivered by Forest Research.

Headline Facts and Figures

Structure and composition of the Monmouthshire study area’s urban forest in 2021		
Estimated total number of trees	80,010	
Estimated tree density (trees per ha)	43.8	
Estimate of total tree canopy cover	10.4%[1]	
Number of tree species surveyed	60[2] 78[3]	
Number of tree genera surveyed	43	
Top three most common species surveyed	Hawthorn spp., Field maple, Ash spp.	
Land uses where a greater percentage of surveyed trees were found	Residential, Parkland, Agriculture	
Percentage of surveyed trees of different sizes (by DBH)	7-20 cm, 54%; 20-40 cm, 31%; 40-60 cm, 9%; >60 cm, 6%	
Percentage of trees in good or excellent condition	69%	

Estimated ecosystem service provision amount and value in 2021			
Annual avoided runoff	38,743 m^3	£56,900	
Annual pollution removal	24 tonnes	£94,000	
Annual net carbon sequestration	675 tonnes	£606,400	
Carbon storage	26,783 tonnes	£24.0 million	
Replacement cost	CAVAT amenity value of all trees: £2.4 million Structural value[4] of all trees: £56.4 million		
Total annual benefit[5], and Benefit: Cost ratio	Total per year benefit to Monmouthshire: £757,300 Management and maintenance budget for Monmouthshire’s public trees: £117,300[6] Benefit: cost ratio of Monmouthshire’s public urban forests to costs is 6.5:1		
Greatest non-UK pest/pathogen threat	Asian longhorn beetle, 60% of trees at risk, with value of £349.8 million		
Greatest pest/pathogen threat already in Wales	Ramorum disease, 40% of trees at risk, with value of £177.4 million		

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. 6. Cost estimate for tree team, back office, highways inspection, and framework contractors based estimated County spend: £326k per annum and calculated 36% of Monmouthshire residential addresses in the study area.

How can this report be used?

This report provides baseline information on the structure, composition, quantity, quality and benefits delivery of Monmouthshire’s dynamic urban forest. By raising awareness of the value of benefits its urban trees provide, the report can help promote, optimise, and equalise investment in green infrastructure.

The assessment presented in this report offers 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.
- Finding locations which would benefit from further green infrastructure.
- Optimising existing, and new, green infrastructure.
- Offsetting known forecasts of loss of tree cover development or 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

- When measured by i-Tree Eco, the canopy cover of the Monmouthshire urban study area is low, even when compared to other coastal areas in Wales.
- Monmouthshire’s urban forest is relatively species rich however, its diversity is unbalanced with a few small stature taxa like hawthorn dominating. This impacts on ecosystem service provision, amenity value and forest resilience.
- There is shortage of large trees, except in cemeteries, which lack small trees.
- The majority of trees are privately owned, with implications for management.
- The amenity value of the urban forest is relatively low.
- There as a higher-than-average proportion of the urban forest at risk from the two greatest health risks; Asian longhorn beetles and Ramorum disease.

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 benefits green infrastructure, the urban ecosystem, and society (Doick *et al.* 2016). 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 the urban areas of Monmouthshire in 2021. **It aims to provide a 'baseline' understanding of the Monmouthshire study area's urban forest**, describing its structure, and then quantifying some of the significant ecosystem services that Monmouthshire's trees provide.

i-Tree Eco was developed by the USA i-Tree Cooperative[1] to assess the make-up of urban forests and estimate and value some of its benefits. 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 hundreds of cities globally.

Approximately half of Monmouthshire's population of 95,164 resides in urban areas (Welsh Government 2021; Visit Monmouthshire 2022). Between 2018 and 2028 this is likely to be the fourth fastest growing Welsh LA population, and the fastest increasing for the over 75s (Statistics for Wales 2020). According to Monmouthshire's 2020 Replacement Local Development Plan, by 2033 it is most likely that there will 7,605 additional homes by 2033 (Monmouthshire County Council 2020a). With increases in population size, population age, building extent, and traffic comes additional pressure on the urban forest. The risk of future losses to Monmouthshire's urban forests may be concerning, considering that tree cover has decreased by 5% in Monmouthshire this century (World Resources Institute 2022). However, there is growing support for expanding and improving urban green infrastructure. In part through the Gwent Green Grid Partnership, volunteer groups (Monmouthshire County Council 2022a), and Monmouthshire CC (Abergavenny Chronicle 2022), tree populations have increased in urban areas.

[1] the Cooperative is an initiative involving USDA Forest Service, Davey, Arbor Day Foundation, the Society of Municipal Arborists, International Society of Arboriculture and Casey Trees.

At the UK-scale, multiple targets, 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 a woodland canopy cover target of at least 12% by 2050. Furthermore, £6 million is allocated to the Urban Tree Challenge Fund (DEFRA 2021), aiming to plant 44,000 large ‘standard’ trees over two years (Forestry Commission 2019).

i-Tree Eco projects can provide further understanding of urban forests and facilitate 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 Monmouthshire’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). Quantifying and assessing the value of the services provided by the natural capital of Monmouthshire’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 Monmouthshire.

Ecosystem service	Role of urban trees	Significance to Monmouthshire
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 due to increase by 10% by 2100 (Intergovernmental Panel on Climate Change 2014). During February 2020 record highs for monthly mean flows, and 15-min peak flows, were exceeded for multiple South Welsh rivers (Sefton *et al.* 2021). In February 2020, 3,130 Welsh properties were flooded, with a relatively large percentage, 15%, falling in Monmouthshire (Natural Resources Wales 2020). Considering an average household flooding claim of £32,000 (Association of British Insurers 2020), a single month likely costs Monmouthshire £14.4 million, in addition to damage to infrastructure.
Air pollution removal	Trees intercept air pollutants, reducing exposure of pollutants to people that can be harmful to health.	Air pollution is linked to ca. 36,000 UK deaths annually (Public Health England 2019). Chepstow and Usk contain Air Quality Management Areas (AQMAs) which have been declared due to NO_2 objective levels being exceeded (Monmouthshire County Council 2022b). Air pollution is linked to ca. 36,000 UK deaths annually (Public Health England 2019).
Carbon storage & sequestration	Trees remove CO_2 from the atmosphere and store carbon in their wood, helping to mitigate global climate change.	A doubling of pre-industrial atmospheric CO_2 levels is likely to lead to 2°C of warming, and in turn, rising sea levels, extreme weather, food shortages, habitat loss, and extinctions (Intergovernmental Panel on Climate Change 2014). Monmouthshire's ecological footprint was one of the highest in Welsh LAs (Statistics for Wales 2014), but since 2005 emissions have fallen by 32% to 0.6 million tonnes CO_2e per capita in 2019 (Monmouthshire County Council 2021).
Habitat provision	Urban trees support a range of biodiversity in urban	Up to 22% of European plant species could be committed to extinction by 2050 with a mid-intensity climate change projection (Thomas *et al.*

	areas, providing opportunities for residents to engage with nature.	2004). 42% of European tree species are currently classed as threatened (Rivers *et al.* 2019). Monmouthshire contains important conservation areas including part of a national park as well as an area of outstanding natural beauty, 55 sites of special scientific interest and 4 special areas of conservation exclusive within it (Monmouthshire County Council 2018; Natural Resources Wales 2021). Monmouthshire CC engages with habitat provision, like planting 8,500 trees (Monmouthshire County Council 2021).
Amenity value	The cost of replacing trees accumulated innate value, which rises with its size, health, accessibility, potential, and character.	In a UK public perception of urban forests survey, 40% of 6,000 participants wanted more and larger trees (Ambrose-oji *et al.* 2021). Monmouthshire contains several ancient trees including yews, catalpas, and pears (Monmouthshire County Council 2020b; Woodland Trust 2022).

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

Ecosystem service	Role of urban trees	Significance to Monmouthshire
Cultural value	Trees improve social cohesion by providing meeting spaces. Trees help create a sense of place, and old trees help create links 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 (Ambrose-oji *et al.* 2021).
Noise reduction	Trees can act as a barrier to noise and reduce stress levels from heavy traffic.	South East Wales contains major roads like the M4, which is disproportionally busy, containing 47% of Welsh traffic (Welsh Government 2020). 24% of Welsh residents report they are regularly bothered by noise. In Monmouthshire, 44 noise

		complaints are made per 10,000 population annually, which ranks mid table amongst Welsh LAs (Chartered Institute of Environmental Health 2020).
Educational value	Trees and woodlands create learning opportunities for children. Adults' involvement and training in tree management can also develop skills.	The Public Opinion of Forestry Survey found 47% of Welsh respondents stated woodlands can be used by schools/ educational groups, and 25% believe they support the local economy (Forestry Commission 2017). Trees are important resources for engaging and learning for example, the Woodland Trust's awards, community projects has reached 70% of UK (Reid *et al.* 2021).
Local climate regulation	Urban areas are often warmer than rural. Tree canopies cool air through shade and evapotranspiration. This improves people's comfort and reduces energy consumption.	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 Island (UHI) was 9°C (Greater London Authority 2006), was attributed to 70,000 deaths. A review of 75 articles found that vegetation cover was 'crucial' for reducing surface temperatures by up to 24°C (Deilami *et al.* 2018).
Enhancing the landscape	Urban trees can improve the peoples' perception and enjoyment of places, raise property values, and increase commercial footfall.	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).
Recreation	People are more likely to exercise in greener environments, improving resident's physical and mental health (Kondo *et al.* 2018).	Activity levels in Monmouthshire were ranked in the bottom 50% of Welsh LAs, and were decreasing further (Statistics for Wales 2014). Recreation, especially for children, is publicly recognised as a benefit from urban trees (Ambrose-Oji *et al*. 2021). 22% of Wales' population frequently use the outdoors for recreation (Natural Resources Wales 2016).

Figure 1. Visual examples of tree ecosytem services. Clockwise from top left: 1) linear features of trees can reduce noise and atmospheric pollution, like that from roads; 2) tree roots stabilise soils on slopes and banks, and reduce flooding by water absorption; 3) trees are some of the richest habitats, providing structural space and food, such as this mistletoe growing on hawthron; and 4) canopies can 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 the 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 forest provides to the residents of, and visitors to the urban areas of South Monmouthshire.

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 Monmouthshire’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

- Risk management: identify risks to the tree population such as climate change or pests and diseases, and to plan accordingly.

- 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.

Social objectives

- Education and advocacy: raise the profile of Monmouthshire's urban forest as a key component of green infrastructure providing benefits to locals.
- Policy: establish new policy to protect and expand all aspects of Monmouthshire'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?

i-Tree Eco was initially used in the UK, in 2011 on Torbay. It has been applied in over 40 UK projects, including in London, Cardiff, and Edinburgh. Peer-reviewed articles have synthesised the findings of several studies, and identified many of the outcomes that i-Tree Eco projects can provide (Hall et al., 2018; Hand & Doick, 2018, Chambers-Ostler & Doick, 2021), 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 informed local and regional reports on these threats, and 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.
- Justifying investment in the urban forest, such as securing two £25,000 budget increases in Torbay, or a new arboricultural officer 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 LA reports including climate change, open space strategies, landscape design and neighbourhood design strategies. Such conversations also encompass Business Improvement Districts, Community groups (such as the Sidmouth Arboretum) and design teams.

Further Information

Additional information on i-Tree Eco and the full range of i-Tree tools for urban forest assessment is located at: www.itreetools.org. The website includes many of the reports generated by the i-Tree Eco studies conducted around the world.

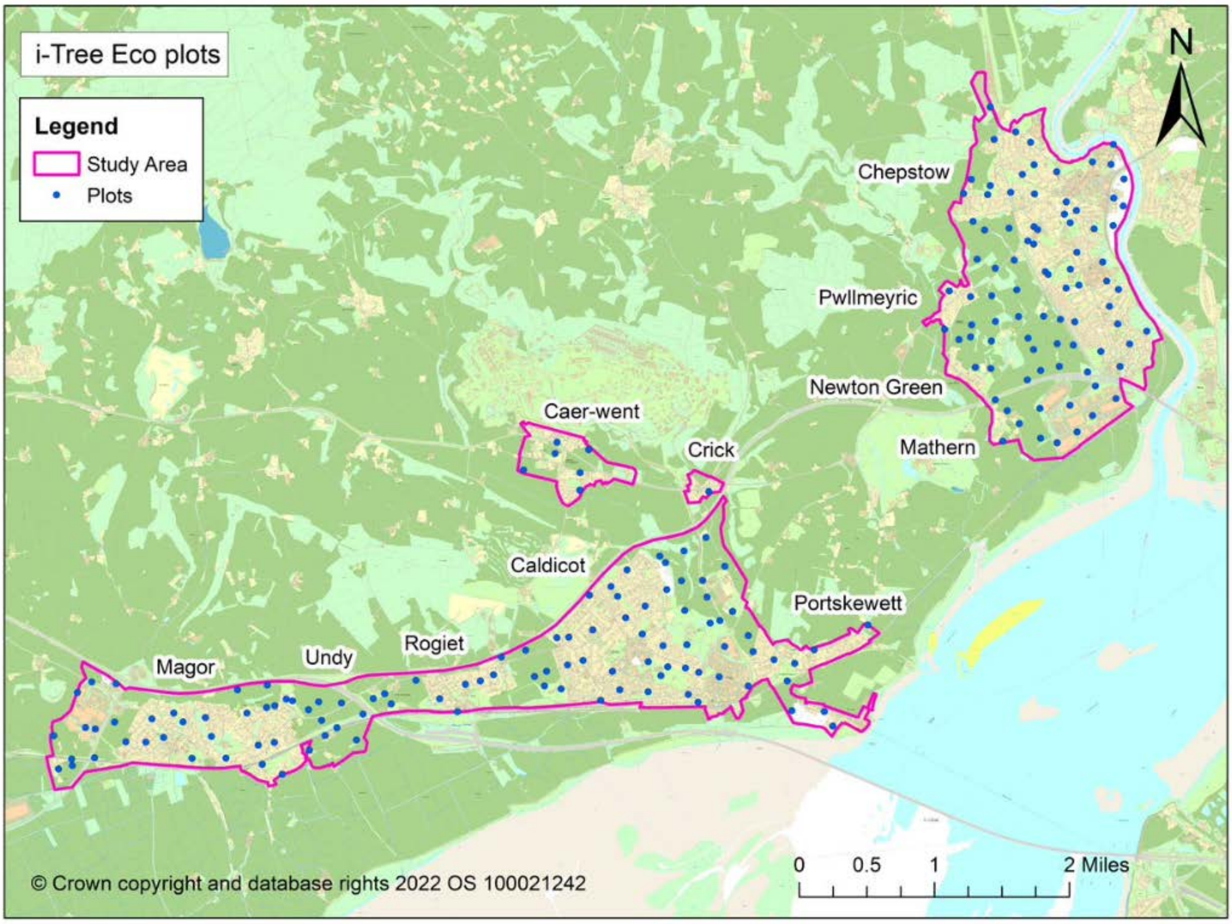
For further details on i-Tree Eco in the UK, on-going i-Tree Eco model developments, training workshops, or to download reports on previous UK i-Tree Eco studies visit www.forestresearch.gov.uk/research/i-Tree-eco.

The identification, measurement, mapping and caring of trees in the urban environment creates 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, a grid was created in a geographic information system (GIS) containing 200 grid cells over the 1,825 ha study area. Each was then randomly assigned one sample plot, providing a sample density of one plot every 9 ha. This sample density is higher than most previous studies and thus provides a more detailed understanding of the urban forest in this area (Table 5). The boundaries adopted for the study, and the location of the plots are presented in Figure 2.



© Crown copyright and database rights 2022 OS 100021242

Figure 2. The Monmouthshire study area, with focused on sampling urban sites in the South, spanning from Magor, through Undy, Rogiet, Caldicot, Crick, Portskewett, Pwllmeyric, to Chepstow.

i-Tree Eco Data Collection

Within each of the 200 plots a succession of measurements were taken including land use and vegetation cover at the plot level, as well as tree and shrub biometrics therein. 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 required 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 from each:

- Within each plot, the percentage of ground in the circle which contains:
    - Each 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	Urban ground cover types. Species diversity, canopy cover, age class, condition, importance, and leaf area. % leaf area by species.
Annual ecosystem services	Rainfall interception from local climate data in i-Tree Eco, and avoided volumetric sewerage charges value in £ from the main local water company. Meteorological data from St-Athan (USAF: 037160) weather station. 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. Annual carbon sequestered and value in £, values of per metric tonne of CO_2 (UK's Business Energy and Innovation's Valuation of Greenhouse Gas Emissions).
Replacement costs and functional values	*Replacement cost based upon amenity value in £ (a CAVAT - Capital Asset Value for Amenity Trees - assessment).* Replacement cost based upon structural value in £ (CTLA - Council of Tree and Landscape Appraisers Method). Current carbon storage value in £, values of per metric tonne of CO_2 (UK's Business Energy and Innovation'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, oak processionary moth, Ramorum disease, Dothistroma needle blight, Phytophthora kernoviae.*

---

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 parallel 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 informed councils' planning decisions. CAVAT provides a value for trees in towns, based on an extrapolated and adjusted replacement cost. This value relates to the replacement cost of amenity trees, rather than their worth as property per se (as per the CTLA method). Particular differences to the CTLA trunk formula method include the addition of the Community Tree Index (CTI) factor, which adjusts the CAVAT value to consider 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 described 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 Monmouthshire or the wider UK. The authors devised a risk matrix for determining the potential impact of priority pests and diseases, should they become established in the urban tree population of Monmouthshire.

Habitat Provision

Trees and shrubs are valuable structural habitats for animals and epiphytic (attached to plants) lichen and moss (Sales *et al.* 2016). Moreover, trees and shrubs are a huge accumulation of biomass accessible for consumption by mammals, birds, and insects. Moreover, 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), Wrexham (Rumble *et al.* 2015), Newport (Buckland *et al.* 2020), and London (Rogers *et al.* 2015)

Summary of the Report's Calculations

Table 4. Summary of the calculations in the report.

Variable	Calculated from
Number of trees	Estimated total tree number extrapolated from the plot sample.
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 Welsh Water (2021) (£1.47 per m^3).
Carbon storage & sequestration values	The baseline year of 2021 and the respective values of carbon per tCO_2 of £245 (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 the Monmouthshire study area's i-Tree Eco survey, compared to four examples across the range of previous UK surveys.

	Monmouthshire	Newport	Wrexham	Cardiff	London
Study area size (ha)	1,825	4,854	3,833	14,064	159,064
Number of trees ('000's)	80[1]	259	364	1,410	8,421
Plot density (ha per plot)	9[2]	24	19	71	221
Canopy cover (ha)	190	582	652	2,658	22,326
% Tree canopy cover	10[3]	12[3]	17[3]	19[3]	14[3]
Number of trees per ha	44	54	95	100	53

Table 5 highlights that Monmouthshire is a moderately sized study area, with a high sampling density. It contains a relatively low canopy cover and tree density.

1. Extrapolated from 349 trees in sample area.
2. Based on 200 plots.
3. Based on calculation from i-Tree Eco sample.

Canopy Cover

The tree canopy cover of Monmouthshire reported by i-Tree Eco surveying was 10.4%. When comparing like-with-like Monmouthshire's canopy cover is low relative to: Cardiff, (19%); London (14%); Newport (12%), 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 16 urban wards of Monmouthshire was 18.6%**[1]**.** This urban mean is slightly less than the 20.1% mean of the eight rural wards in the LA.

At the country level, Monmouthshire's urban canopy cover is just below the average of 19.0% for Wales. Moreover, across Welsh LAs, Monmouthshire's canopy cover is relatively rural-biased. However, at the UK scale, Monmouthshire's urban canopy cover is greater than 17.0% average. Furthermore, when urban localities across the UK are ranked in descending order on the UK canopy cover webmap[2] Monmouthshire achieves 111th out of 341. This rank is tied with five other areas, including Bristol City (Urban Forest Research Group 2022).

Ground Cover

Ground cover in Monmouthshire consisted of 56% 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 Monmouthshire falls close to the centre of previous i-Tree Eco surveys, for example: Wrexham (52%), Newport (46%), Cardiff (59%), and London (60%).

Land Use

The three most common land uses in the sample plots were residential (29%), agricultural (27%), then transportation (14%) (Figure 3). Additionally, in the subset of **plots containing trees, the three most abundant land uses were residential (51%), parkland (12%), followed by agricultural (11%)**. Consequently, the majority of plots, and plots with trees, were within the top two

---

[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).

land uses in each category. The average canopy cover of residential, park, and farm land was 11%, 22%, and 9% respectively. Although only accounting for 1% of land, cemeteries had the greatest canopy cover of 43%. Similarly, the next highest canopy cover, 34%, was in institutional, which just made up 3% of land use. For the top three land uses, the mean plantable space, permeable ground with an unobstructed space above, was: residential land, 14%; parkland, 34%; agricultural land, 31%. Despite being just 5% of land use, vacant land had the greatest plantable space of 56%.

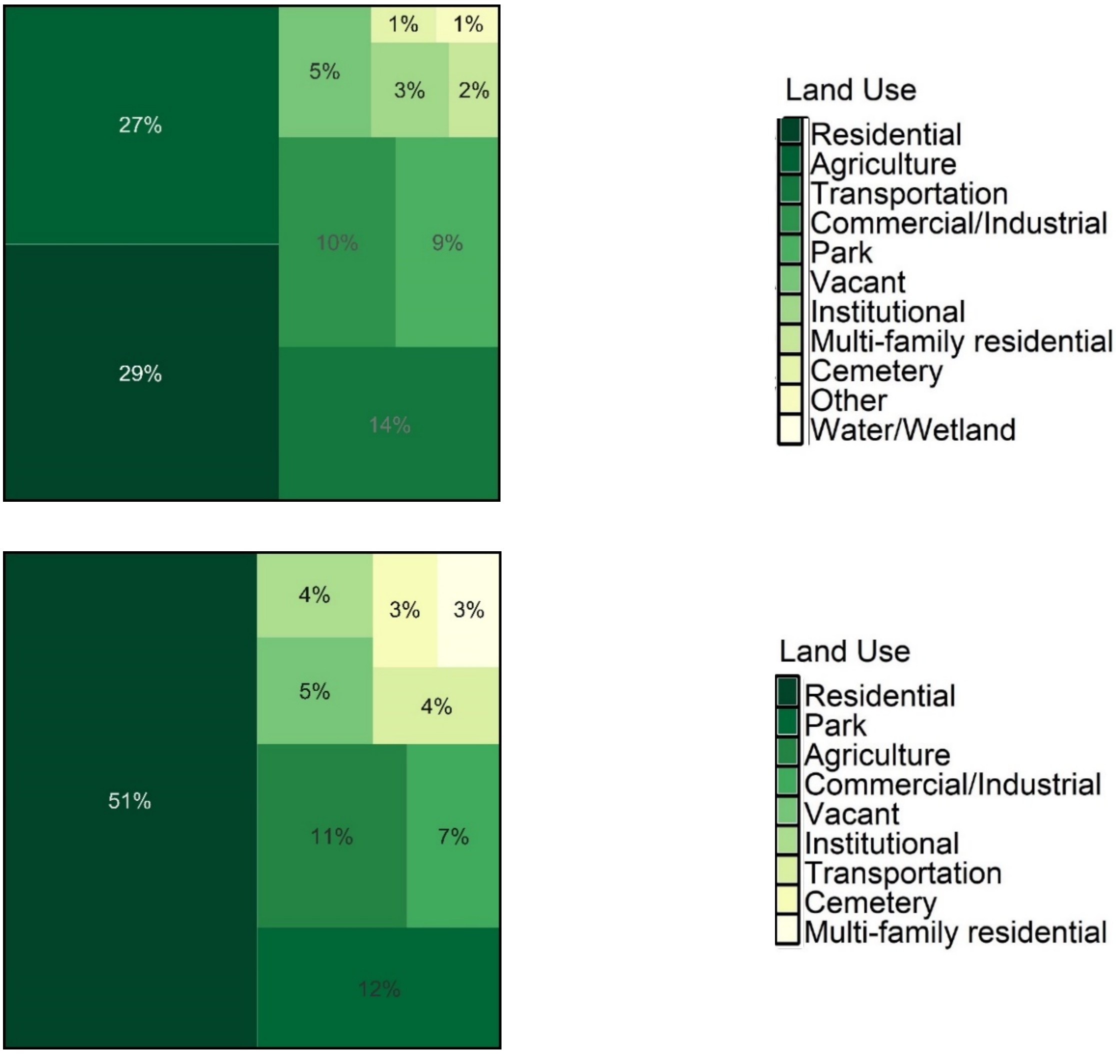


Figure 3. Percentage of plots falling into each of the different land uses, for both all plots (top) and only for the subset of plots which contained trees (bottom). Plots could contain more than one land use, for example, stranding the boundary between a private residence and school. Each plot was defined 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 60 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 78 (including ‘spp.’ where an identification beyond genus was not possible). Monmouthshire’s unique entry species richness of 78 was higher than previous i-Tree Eco reports for Newport (59), Cardiff (73), and Wrexham (54). However, Monmouthshire richness was lower than recorded in the London (126). Of the 43 genera present, the most abundant genus was maples (*Acer*), with four species present, and a high number of field maple (*A. campestre*). The next three most abundant genera were hawthorn (*Crataegus*), one species; cherries/plums (*Prunus*), ten species; and ash (*Fraxinus*), one species.

The ten most common tree species accounted for the majority (65%) of the trees surveyed (Figure 4). Santamour (1990) recommended that for urban forests to be resilient, no species should exceed 10% of the population, no genus surpass 20%, and no family top 30%. Field maple and hawthorn exceeded the 10% guideline, and maples surpassed the 20% genus aim. The rose (Rosaceae) family was also overabundant, because 32% of individuals, like hawthorns and cherries/plums, belonged within it.

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 *et al.* 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).

The mean H score of the Monmouthshire study areas’ urban forest was 3.3 (Table 6). This diversity value is relatively low compared to previous urban forest reports; Cardiff (3.3), London (3.9), Newport (3.5), Wrexham (3.1).

---

[1] 60 tree species identified at the species level of precision. There were 78 unique entries which also contained general species ‘spp.’ where the species could not be identified.

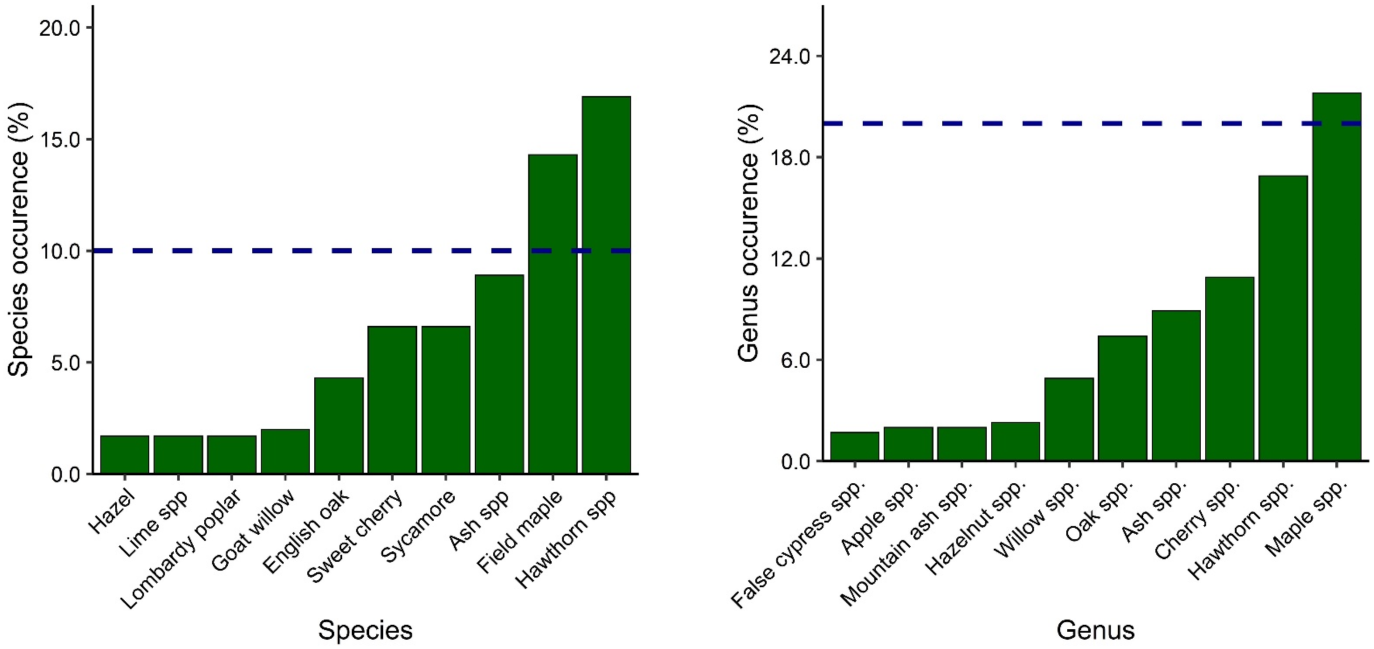


Figure 4. Contribution of the top ten most abundant trees as a percentage of the total tree number, for tree species (left)[1], and for tree genera (right).

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

Land Use	SW Index
Residential	2.9
Institutional	1.9
Park	1.8
Agriculture	1.7
Vacant	1.6
Commercial/Industrial	1.5
Cemetery	1.3
Transportation	1.0
Multi-family residential	0.7
Total	**3.2**

Figure 5. A divserse showcase of shape and colour in Monmouthshire. Clockwise from top left: Japanese maple, Judas tree, American sweetgum, Atlas cedar, Russian olive, laburnum, Wych elm, and Silver maple.

[1] Genus ‘spp.’ stands for one or more species within the genus.

Targeting management for greater diversity

Understanding where species diversity could be improved can help to inform urban forest management at a local (e.g. ward) and city-wide scale. In the Monmouthshire study area, currently there is an overabundance of certain groups at species, genus and family level; especially hawthorn and field maple. Such bias towards a couple of species reduces the urban forests resilience to changes from disease and climate change, lowers its public amenity, and reduces the diversity of species which it can support. Where feasible in public spaces, the LA could plant alternatives, and manage the growth of existing over-abundant species. Progress could be monitored through inventories. In private spaces, the use of alternative species could be promoted and incentivised through education and outreach to developers and residents. The balanced presence of many tree species, termed diversity, is important for resilience and adaptation, however, so too is genetic diversity within species, which can be promoted through the informed use of different cultivars and varieties. Ecosystem service provision, and tree health, is further enhanced by tree arrangement, such as with connected ‘green corridors’.

Land use and Ownership

Residential, agricultural, and transportation were the most common land uses. However, they did not necessarily have the most abundant or rich urban forest community. The most tree-abundant land uses were residential, park, then agricultural, whereas **the most species-rich land uses were residential, agricultural, then parkland (Table 7). The species composition varied between these land uses (Table 8). Monmouthshire’s publicly accessible land (parks, vacant, cemeteries, and transport), contained only 28% of the total tree abundance, and less than half of the total tree richness.** This urban forest is biased toward private ownership, considering that a recent review found that across UK i-Tree Eco studies, 21 to 75% of trees were publicly accessible (Vaz Monteiro *et al.* 2019).

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	Agricultural	Park
Number of trees	86	106	52
Abundance relative to total	25%	**30%**	15%
Species richness	30	16	13
Richness relative to total	**50%**	27%	22%

Table 8. Contribution of the top five most abundant tree species, towards the three most tree-abundant land uses. Percentages are relative to the within-use total. Green shows tree species present in two land use categories.

Residential		Agricultural		Park	
Species	%	Species	%	Species	%
Sycamore	23%	Hedge maple	28%	Hawthorn spp.	29%
Apple spp.	6%	Hawthorn spp.	25%	Field maple	23%
Common plum	5%	Ash spp.	13%	Ash spp.	12%
English oak	5%	Sweet cherry	8%	Lime spp.	6%
Rowan	3%	Common hazel	5%	Rowan spp.	6%

Origin

Of those trees identified to species level in the Monmouthshire i-Tree Eco study, it is estimated that 64% are native, and an additional 16% are naturalised, according to the UK tree list in Johnson and More (2006)[2].

2. The source material to generate the native list differs slightly from previous studies.

The origin of species

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 trees are likely to resist diseases because of enemy release; they have fewer pests associated with them in novel areas as their home range interactions are unlikely to be present, and evolutionary time is needed for local organisms to recognise and exploit the exotic host (Connor *et al.* 1980; Mitchell & Power 2003). Also, trees from warmer climates may be better adapted to the temperature and drought predicted with climate change (Buras & Menzel 2019; Royal Horticultural Society 2021). Conversely, there are ample examples of exotic trees species becoming invasive (for example Jumbay trees, Rhododendrons, and Lodgepole pines), with impacts on native species such as intensified competition for resources like light, and shifts towards unfavourable environmental conditions like soil chemistry (Begon *et al.* 2006; Rundel *et al.* 2014; Kew Royal Botanic Gardens 2017). 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 & Southwood 1984).

Figure 5 highlights a range of trees, which besides the Wych elm, are not native. Examples of exotic trees within Monmouthshire plot data include those native to Asia like the gingko (*Ginkgo biloba*), and those originally from Americas such as the monkey puzzle tree (*Araucaria araucana*). Monmouthshire has a relatively high percentage of trees which are native, considering other studies, such as Edinburgh (53%), Cardiff (56%), Wrexham (59%), but not London (39%).

Size Class Distribution

Richards (1983) recommended that the distribution of urban 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. **In Monmouthshire, it is estimated that trees with a DBH of 60 cm made up 6% of the tree population (Figure 6), which is below to the 10% guide.** This figure is in the range of previous studies (Cardiff, London, Newport and Wrexham), which report a 6 to 7% value. The proportion of trees is less than half the recommendation for **40-60 cm DBH, and 14% higher than the aim for the 7-20 cm DBH class.** In summary, there are too few large, and too many small, stature trees in general. The distribution of tree sizes varies across the different land uses of Monmouthshire (Figure 7). Commercial land conforms most accurately to the 40-30-20-10% ascending size class guide, the splits being 40-24-32-4%. The most deviant land use is cemetery with a very large-tree skewed distribution of 0-0-40-60%. Conversely, agriculture size classes are skewed towards small trees with 76-14-4-6%.

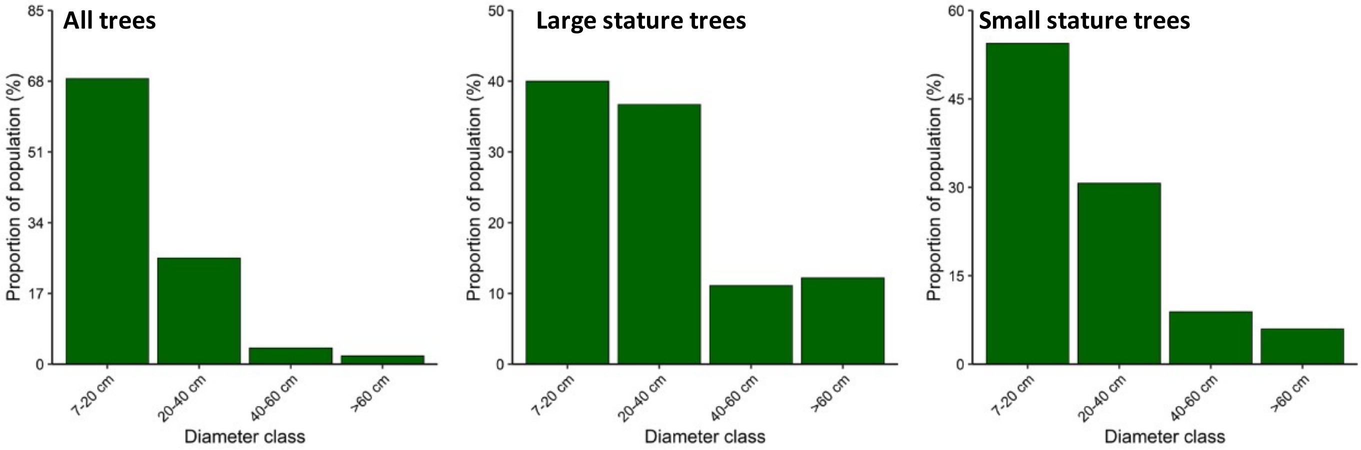


Figure 6. The percentage of the tree population per DBH class for all measured trees (left), large stature species only (middle), and small stature species only (right). Stature categorisation is based on the maximum reported height of a species, where large trees exceed 12 m.

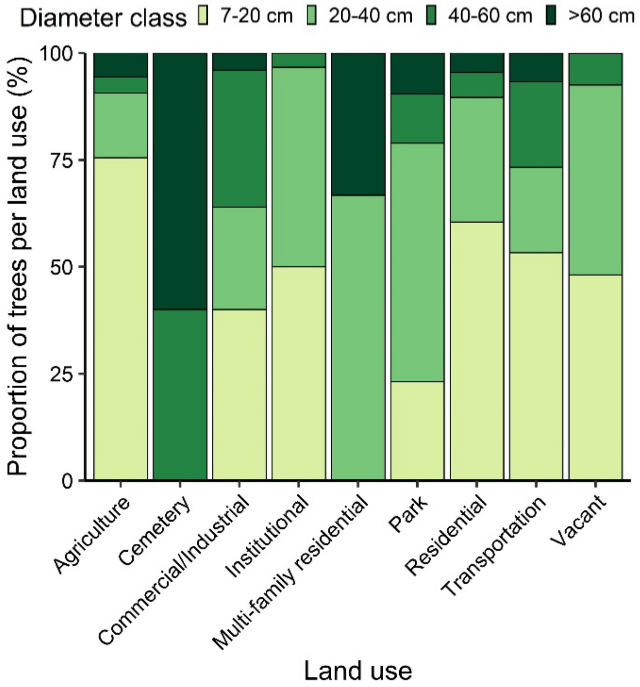


Figure 7. Percentage of DBH size classes per land use type. Land uses were defined by the dominant function in each plot.

Size matters

The size distribution of trees is important for a sustainable forest community and effective ecosystem service provision. Large or mature trees provide greater ecosystem services relative to smaller or younger trees (Hand *et al.* 2019). Therefore, planting more large stature trees, and supporting the development of wide trunks, large canopies and long lives, maximises ecosystem service provision and amenity value. Furthermore, ensuring sufficient small trees are present will facilitate recruitment of larger trees, a more varied habitat structure, and a sustainable urban forest long term. In Monmouthshire there is a general overabundance in small trees, leading to inefficiencies in ecosystem service provision. An abundance of small DBH tree may not ensure future recruitment either, as it is likely that many individuals are small stature species like hawthorn. Planting and development should account for the space required by future large mature trees in good time, to minimise the impact of the trees' vigor on infrastructure and vice versa. Cemeteries in particular pose a reverse issue in that there are no trees below 40 cm, which, without new tree planting, is a risk to the long-term persistence of its urban forest.

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 positively associated with ecosystem service delivery, for example the carbon storage in street trees (Smith *et al.* 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, the Monmouthshire study area's crown condition was:

- Excellent: 40%
- Good: 29%
- Fair: 16%
- Poor: 7%
- Critical: 3%
- Dying: 1%
- Dead: 4%.

Thus, 15% of Monmouthshire's trees are estimated as being in the poor, or worse, condition. Monmouthshire's trees tend to be less healthy than previous i-Tree Eco studies. For example, in Cardiff and Wrexham only 13% of trees were poor or worse.

Of the nine land uses, four contained dead trees, however, all had trees in excellent condition (Figure 8). Condition was fair or better for all trees in the transport and multi-family residential. **Vacant then commercial land had the most trees which were in poor or worse health**; this was 33% of the community in vacant, and 28% of trees in commercial.

The most abundant crown condition across the ten most common species was good, with 34% (Figure 8), however, there were inter-species differences in the crown condition spread. **All species had examples of excellent crowns, but this condition was the most common in limes (100%), sweet cherries (57%), and Lombardy poplars (50%).** Conversely, the three species with the greatest percentage of individuals in poor or worse condition were goat willows (43%), ash spp. (26%), and hawthorn spp. (22%).

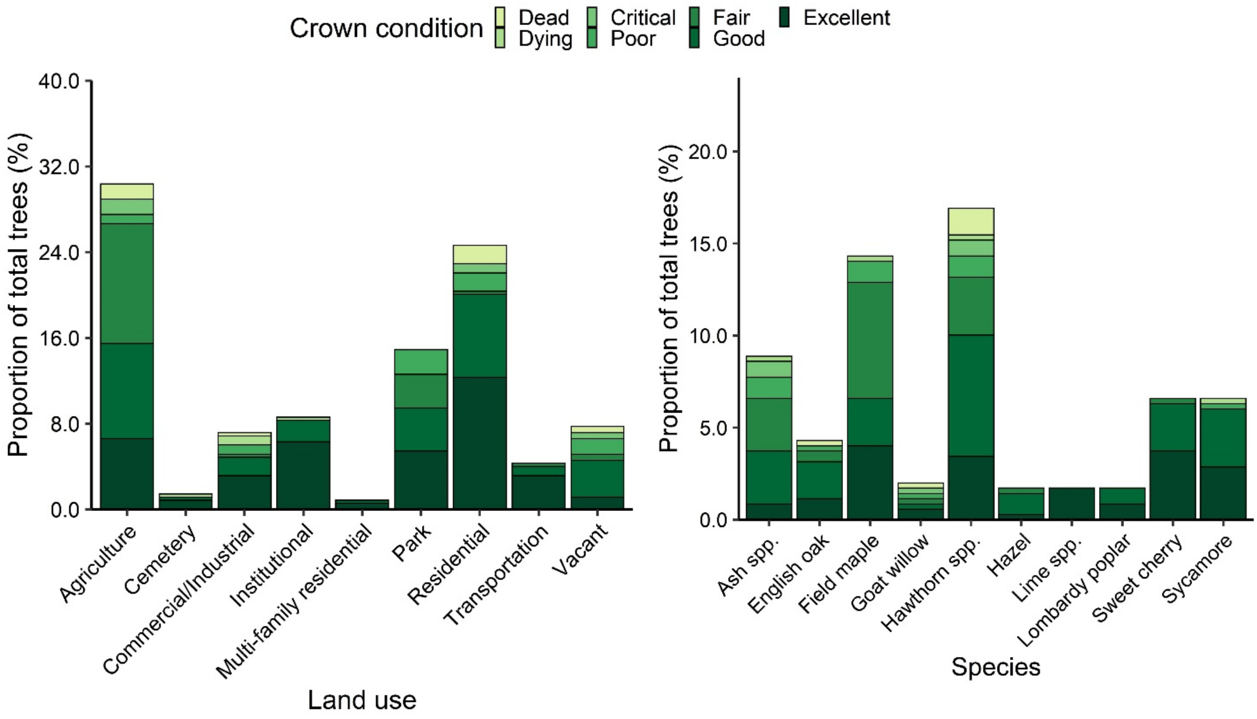


Figure 8. Percentage of trees falling in each crown condition class, by land use (left) and by species (right). Land uses were defined by the dominant function in each plot. Crown conditions: excellent, >99% health; good, 99-90% health; fair, 89-75% health; poor, 74-50% health; critical, 49-25% health; 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, and fungal infections. 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’ real estate 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 indicates the extent to which trees can provide their benefits, such as atmospheric pollutant removal (Nowak *et al.* 2006), rainfall interception (Seitz & Escobedo 2011), as well as cooling through shade provision (Lin & Lin 2010) and evapotranspiration (Moss *et al.* 2019). The total leaf area provided by Monmouthshire’s trees was 23 km^2. **Monmouthshire’s urban tree species which provide the most leaf surface area are lime spp., sycamore then ash spp.; with 17%, 16% and 9% of the total respectively (Figure 9).** Importance value[1] is calculated in i-Tree Eco from the sum of the percentages of leaf area and population, 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 Monmouthshire study, by importance value, are sycamores (large leaves and stature), hawthorn spp. (very abundant), followed by field maple (abundant).

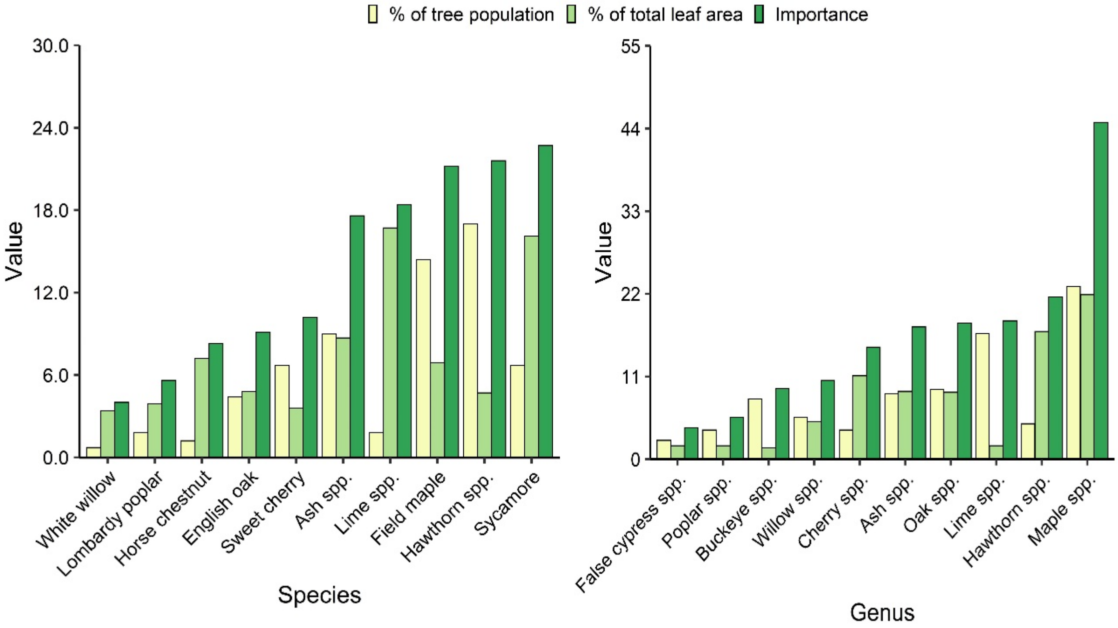


Figure 9. Top ten importance values in Monmouthshire by species (left) and genera (right), along with their percentage contribution towards total population and leaf area.

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

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. Monmouthshire has recent experience of hundreds of flooded homes during the 2020 winter storms (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 *et al.* 2002). This is particularly effective 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).

Monmouthshire's trees

The Monmouthshire study area's trees' intercept an estimated 38,743 m^3 of water per year. This equates to 129 Chepstow Leisure Centre swimming pools[1]. Based on the standard local rate charged for sewerage[2], **this saves £56,899 in avoided sewerage charges** across Monmouthshire each year. By individual tree species, lime spp. intercept the most water (6,409 m^3 per year), worth £9,412 in avoided sewerage charges (Figure 10). Limes' importance to Monmouthshire is because of their large stature and leaf area; their standing here is noteworthy because across four other Eco studies (see Methods) sycamore, common beech, oak, and ash were the leading interceptors.

[1] Poolfinder | Chepstow Leisure Centre (swimming.org) leisure/gala 20*10*1.5 m = (300 m^3).

[2] Welsh water sewerage cost of £1.47 per m^3 for Wales in 2021/2.

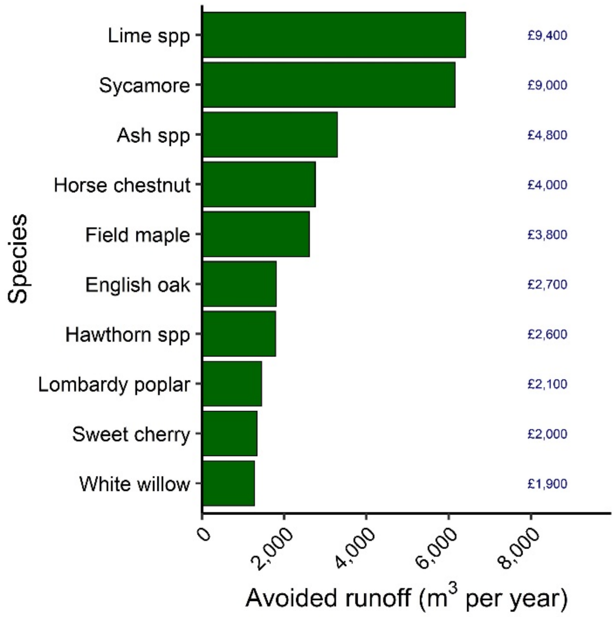


Figure 10. Volume of avoided surface water runoff per year provided by urban trees in Monmouthshire, and their associated value in avoided water waste sewerage costs[1].

Reducing flooding in Monmouthshire

Trees with large canopies are particularly useful in rainfall interception and across Monmouthshire oak trees provide a valuable storm water interception service. With good design, the planting of large stature trees in areas prone to flooding can complement a planning authority's strategy against flooding. Planting should occur where there is appropriate space and species selection must be informed by preference to the local soil, climate and hydro-geological conditions, and flooding tolerance (Niinements and Valladares, 2006).

Planting for interception can be complemented with planning for Sustainable Urban Drainage Systems (SUDS). SUDS are a sequence of management practices, control structures and strategies designed to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local water bodies (CIRIA, 2007). Trees can provide a positive contribution to a SUDS system. The selection criteria must include all three elements of the SUDS principles: quality, quantity, and amenity (including biodiversity) in addition to the usual tree selection considerations mentioned.

[1] Welsh water sewerage cost in 2021/2.

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 associated with 36,000 UK deaths annually (Table 1).

How trees can help

Plants absorb air-borne pollutants through their stomata, or simply intercept pollutants which are deposited on their surfaces (Nowak *et al.* 2006; Escobedo *et al.* 2008). 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 & Winner 2009). However, trees can also contribute to O_3 production by emitting volatile organic compounds (VOCs), which can react with other pollutants such as NO_x (Lee *et al.* 2006). i-Tree Eco takes the release of VOC's by trees into account to calculate the net balance of O_3 gain and loss.

Monmouthshire's trees

It is estimated that the **Monmouthshire study area's urban trees remove 24 tonnes of airborne pollutants, annually**, **with a value of £94,000 per year (value not including CO and O_3).** The pollutants include O_3, NO_2, $PM_{2.5}$, SO_2, and CO, in descending order of removal (Figure 11). Air pollution removal was especially effective in summer, with the mean value for that season being at least double the average of winter (Figure 12). The pattern of air pollutant removal by Monmouthshire's urban forest broadly matches four previous UK i-Tree studies (see Methods); with removal of O_3 and NO_2, and removal during summer, being particularly important. NO_2 is the most critical air pollutant in Monmouthshire, and $PM_{2.5}$ is of national concern.

The methods used to value air pollutants' damage to society differs between countries, here has utilised the UK and Social Damage Costs values (UKSDC) (Birchby *et al.* 2020). 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.

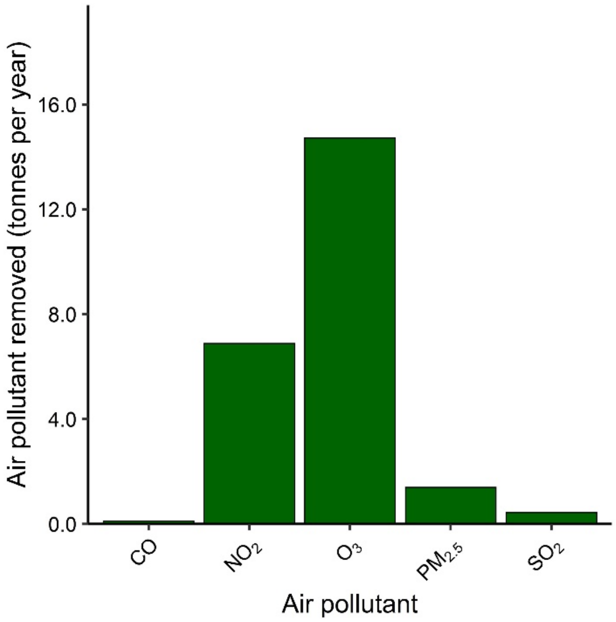


Figure 11. Annual sum of the mean monthly quantity of atmospheric pollutants removed by urban trees in Monmouthshire.

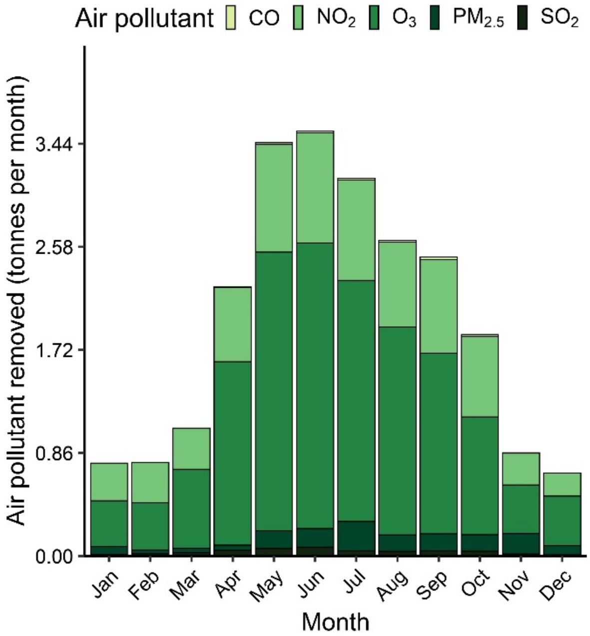


Figure 12. Amount of atmospheric pollutants removed by Monmouthshire's urban trees on a monthly basis.

Air pollution removal by Monmouthshire's urban trees

Air pollution is recognised by the Welsh Government as a critical threat to the health and well-being of urban populations (Welsh Government, 2017). In particular, high levels of NO_2 have led to the designation of two Air Quality Management Areas in Monmouthshire.

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

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 1°C. 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. Monmouthshire 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 & Potvin 2007; Smith *et al.* 2019). Across a city net carbon sequestration can be negative, if emission from decomposition is greater than uptake by growing trees.

Monmouthshire's trees

It is estimated that the **Monmouthshire study area's urban forest stores a total of 26,783 tonnes of carbon in its wood, above and below ground**. This is equivalent to 98,204 tonnes of CO_2[1], which is comparable to the emissions produced by 19,641 households[2], around 51% of the number of properties in Monmouthshire[3], or alternatively, the annual CO_2 emissions of 60,995 cars[4]. The relative amount of CO_2 stored is toward the low end of four previous UK i-Tree studies (see Methods), for example Cardiff's store is equivalent to 140% its households' CO_2 emissions. Carbon storage depends on a variety of factors including the number, species, size, health and timber density of trees present. Although being the most abundant tree, being 17% of the tree community, hawthorn are relatively small and only store 8% of the urban forest's carbon (Figure 13).

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, **the current carbon stock in trees is worth approximately £24.0 million.**

1. Note, the ratio of mass of C to CO_2 is 12:44. 2..Based on an average UK household emission of 5 tonnes of CO_2 per year in 2012 (Palmer & Cooper 2013) 3. 38,233 households estimated in Monmouthshire in 2021 (Monmouthshire County Council 2020c). 4. 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).

Taking into account 206 tonnes of released carbon, from sources like decomposition of dead trees and leaf litter, **Monmouthshire's urban forest is estimated to sequester 675 tonnes of carbon per year, net** (Figure 13); this estimated amount of carbon is **worth £606,400.** The net sequestration rate is equivalent to the estimated annual emissions of 495 households, or instead, the annual emissions from 1,537 cars. Note that the species with the highest sequestration rates are different to those with the greatest stores, and that these fast-sequestering species are leading despite their low abundance.

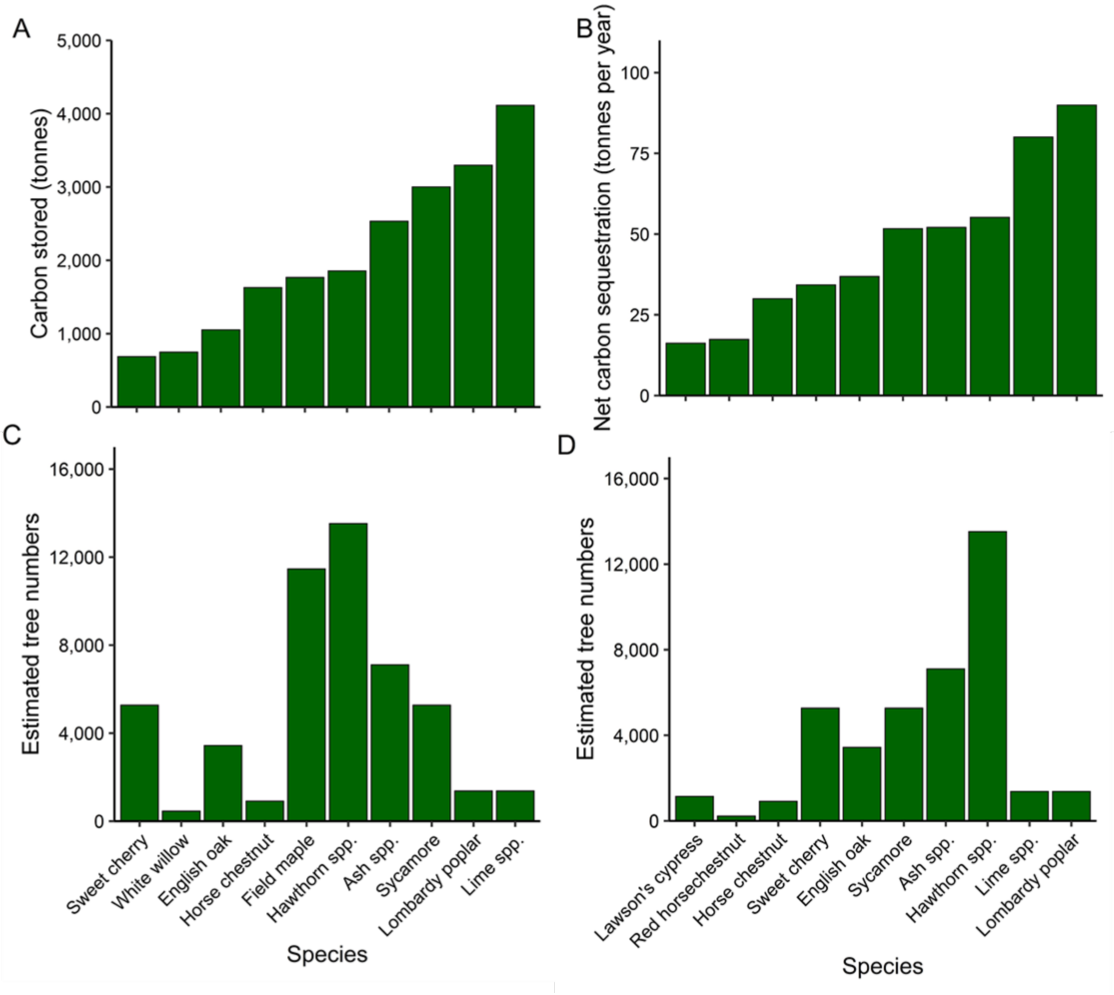


Figure 13. Carbon stored (A) by the top ten species responsible for this storage and their estimated abundance (C) in Monmouthshire's urban forest. Net carbon sequestration (B) by the top ten species responsible for this sequestration and their estimated abundance (D) in Monmouthshire's urban forest. Tree abundances estimated by i-Tree Eco.

Carbon Storage and Sequestration

Carbon has a significant role in climate change. This is due to the absorption of heat by carbon dioxide (CO_2) in the atmosphere, preventing heat from being lost to space, and re-emitting some of this thermal energy back to Earth. As a result, increasing levels of carbon contribute to increasing global temperatures.

The urban forest is an important repository for carbon, and thus helps to combat a key driver of our changing climate. This i-Tree Eco study shows that for Monmouthshire's urban forest, oaks (Irish and English) make a significant contribution to carbon storage and sequestration, in addition to other large stature trees, including sycamore and horse chestnut. There is a significantly high storage and sequestration capacity to tree number ratio for these trees, emphasising the importance of large stature trees in providing ecosystem services. However, species diversity must be carefully considered to ensure resilience and prevent over reliance on certain tree species. For future planting, pioneer species or other fast-growing trees may offer a quicker solution to increased carbon storage capacity, such as birch, willow, pine, spruce and some ornamental choices such as dogwoods and Liquidambars.

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 has recorded 80% decline in European invertebrate abundance over 27 years (Hallmann *et al.* 2017). Consequently, there could be grave consequences for the resilience of ecosystems, on which humans depend. Research looking at 4,424 species in Great Britain over 40 years, found significant net losses 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 *et al.* 2019). Despite their spread, urban areas can be relatively fragmented and hostile for biodiversity, by reducing suitable habitat availability and connectivity, in turn reducing natural populations' resilience (Hill *et al.* 2008; Parmesan *et al.* 2015; Fenoglio *et al.* 2021).

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

Monmouthshire’s trees

The biodiversity value was assessed for several of Monmouthshire’s abundant trees using data on a range of metrics from literature, and the urban forest composition. This analysis provides an indicator of the relative biodiversity value of tree taxa, and their population size in the Monmouthshire study area. 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 the number of invertebrates associated with tree species from Southwood (1961) and Kennedy and Southwood (1984) (Figure 14). Another 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 (Figure 15). These metrics provide a useful indicator of the relative biodiversity value of different trees however, the underlying data vary in time, space, and methods, and may not be specific to urban forests.

Of the tree species considered, the most abundant taxa in Monmouthshire are not necessarily the best for supporting insects. For example, field maple is the second most abundant, 14% of the tree community, but only supports 51 insect species; whereas English and oaks, 5% of the tree community, support 423 insects. (Figure 14). To improve habitat provision for insects, one may consider in future increases the number of trees for groups like willows and birch instead of maples.

Two of the three most common tree genera in Monmouthshire rank relatively high in the provision of nectar/pollen; maples and plums/cherries. Increasing the proportion of apple, lime, and rowan may improve this service. **Similarly, two of the three most common tree genera are rated highly as providers of fruits/seeds; plums/cherries and oaks** (Figure 15). To enhance this food source, one may consider more rowan and apple, in future. Note that the cherry/plum and hawthorn groups perform well as supplying nectar/pollen as well as seeds/fruits.

1. Only the tree species with available insect species supported data are included. Data here are the upper estimate, or idealised, species support. Not all species may be present in Monmouthshire, for example due to climatic reasons.

2. Tree species with a low provisioning here may hold a large quantity of available biomass in structures like foliage and roots for herbivorous consumption.

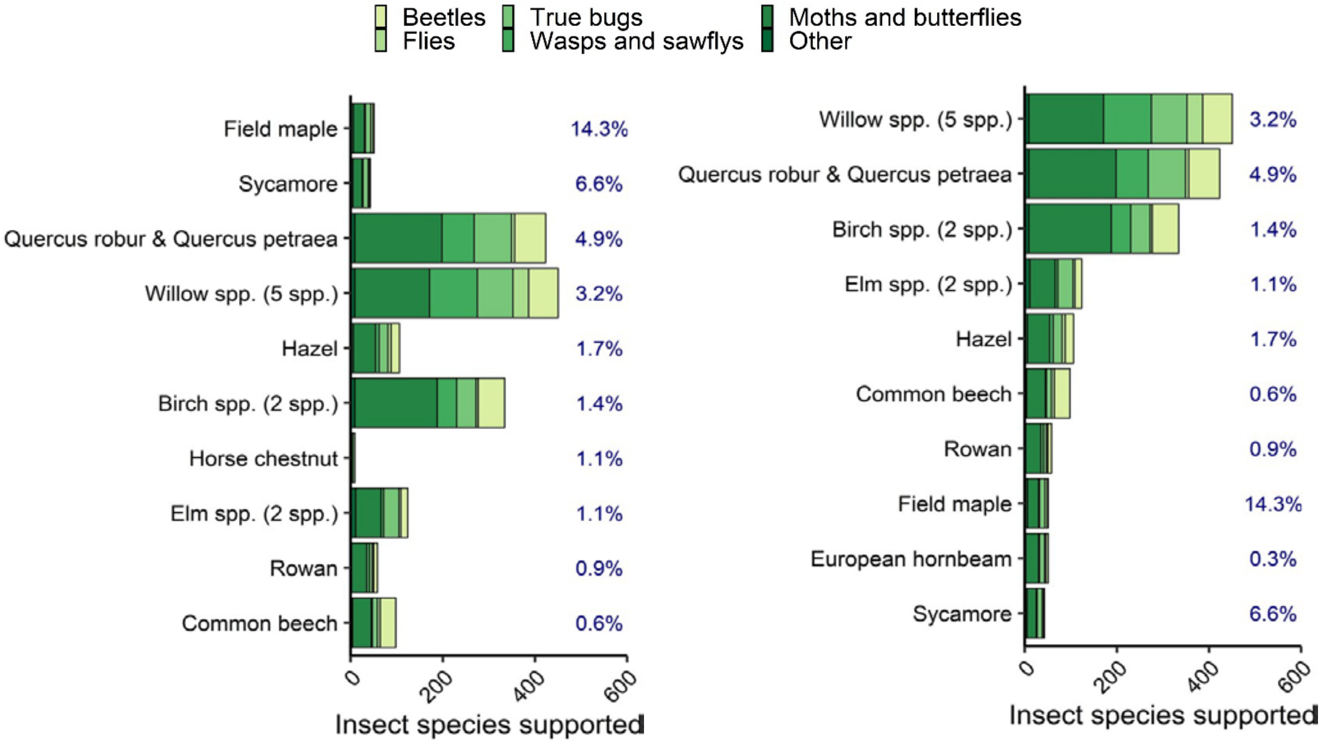


Figure 14. The number of insect species supported, sorted by the tree species' relative abundance (left), or by the richness of insect species each tree support (right). Percentage value in blue indicates the abundance of each tree species relative to the tree population.

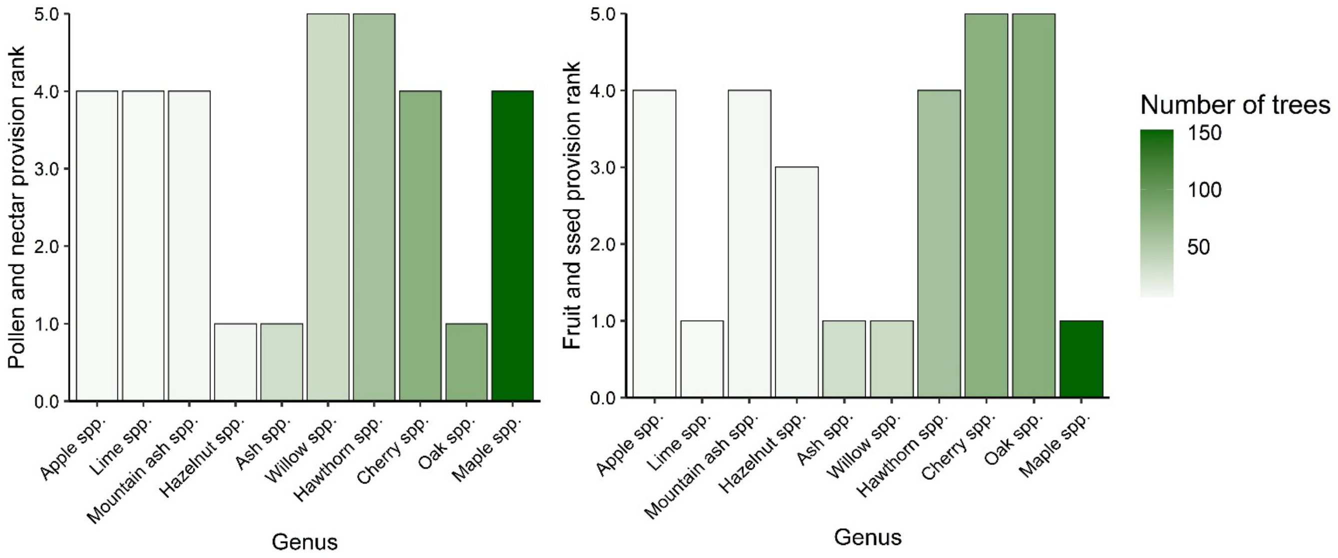


Figure 15. Provision ranking for the ten most populous genera for pollen and nectar (left), as well as fruit and seeds (right); where a rank of five indicates relatively high food provision. Food provisioning described here is mainly mutualistic (co-operative between trees and insects). The colour indicates the number of trees per genus observed in this study.

Replacement Cost and Amenity Value

CTLA Valuation

The **urban forest of the Monmouthshire study area has an estimated replacement value of £56.4 million according to the CTLA** Appraisers' (1992) valuation method. This is the cost of replacing the urban forest of Monmouthshire 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 the Monmouthshire study area has an estimated public amenity asset value of £2.4 milion 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, lime then oak genera had the highest overall amenity value in Monmouthshire** (Table 9; Figure 16). The single most valuable tree encountered in the study was a 22 m-high, excellent condition, lime tree (*Tilia* sp.) on agricultural land in Pwllmeyric; it was estimated to have a CAVAT asset value of £205,032. The high amenity (structural and functional) value of maples, limes and oaks was unsurprising; because they are relatively abundant and healthy in Monmouthshire, and generally tend to have large statures and long lives.

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

The land use type containing the highest CAVAT value of trees was agricultural, being £611,428, and equating to 22% of total value of the whole study. Residential and park land were the next most important contributors for the CAVAT value (Figure 15). These three land uses frequently have large CAVAT values, across the sample of four previous i-Tree Eco studies.

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

Genus	Value of measured trees (£)	Value extrapolated across Monmouthshire (£)
Maple spp.	£421,575	£96,190,858
Lime spp.	£412,306	£94,075,780
Oak spp.	£266,077	£60,710,708
Poplar spp.	£158,127	£36,079,764
Hawthorn spp.	£137,841	£31,451,200
Ash spp.	£136,690	£31,188,538
False cypress spp.	£106,407	£24,278,992
Buckeye spp.	£104,457	£23,833,852
Willow spp.	£98,064	£22,375,233
Cherry spp.	£97,574	£22,263,420

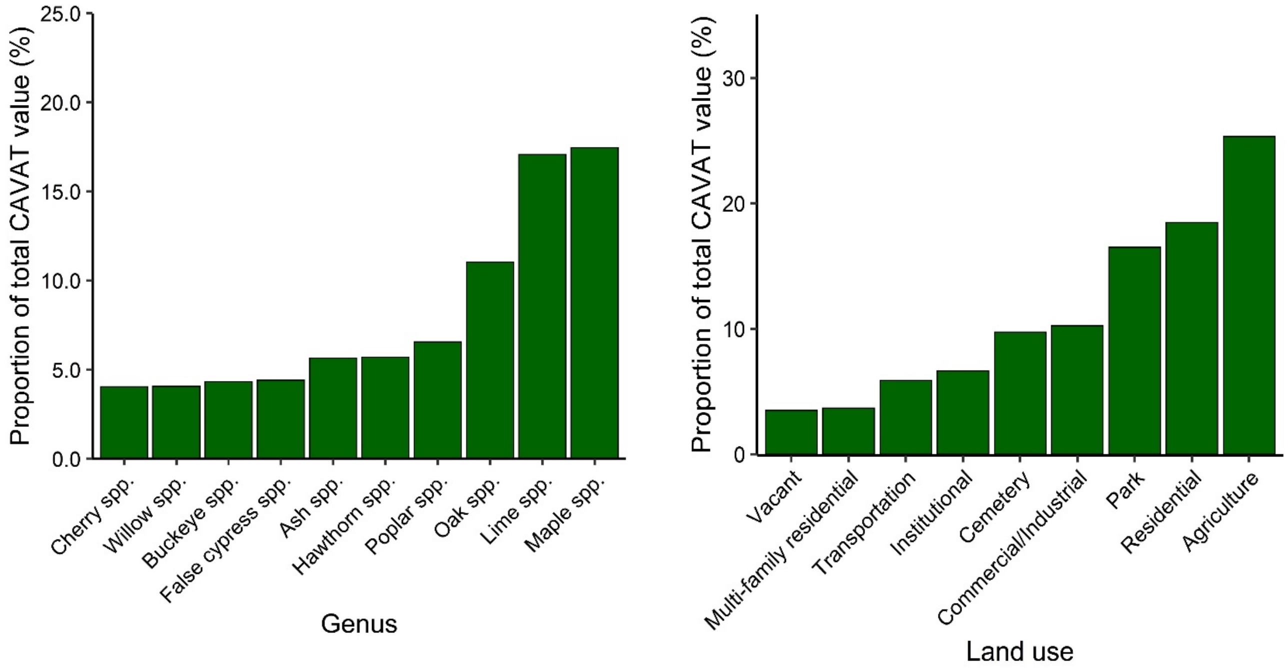


Figure 16. The top ten genera according to CAVAT valuations, and their relative contributions of each component, for the top ten most valuable genera (left), and across land uses. Land uses were defined by the dominant function in each plot.

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.

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 aesthetic, and accessibility.

Pests and Diseases

The Problem

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

As global change is increasing the incidence and severity of tree diseases, assessing the risk that pests and pathogens pose to urban forests is paramount. Risk matrices were devised for determining the potential impact of a pest or pathogen, should it become established in an area, based on whether it affected a single treen genus (Table 10), or multiple genera (Table 11). **This informed Table 12, which gives an overview of the existing and emerging risks to the urban forest of the Monmouthshire** study area, including the predicted proportion of the tree community would be affected.

The UK plant risk register 2021 contains 1,240 entries, and is multifaceted, considering the current extent of a disease, the likelihood of its spread, the severity of its damage, and the ability to mitigate it. Below, a subset of 10 pests and pathogens are tabulated, each is in the top 5% of UK plant risk register and affected more than 1% of the study's tree population. Others assessed, but omitted from the table, include the: red-necked long-horn beetle (*Aromia bungii*), great spruce bark beetle (*Dendroctonus micans*), pine processionary moth (*Thaumetopoea pityocampa*), gypsy moths (*Lymantria dispar*) horse chestnut leaf miner moth (*Cameraria ohridella*), elm zigzag saw fly (*Aproceros leucopoda*), oak lace bug (*Corythucha arcuata*), oriental chestnut gall wasp (*Dryocosmus kuriphilus*), plane wilt fungus (*Ceratocystis platani*), plane lace bug (*Corythucha ciliata*), the gypsy moth (*Lymantria dispar*), rowan ringspot virus, water moulds *Phytophthora austrocedri* and *P. lateralis*, fungi *Sirococcus tsugae* and *Cryphonectria parasitica*, as well as the bacteria *Xanthomonas arboricola pv. Pruni* and *Xylella fastidiosa*. Information has been primarily referenced 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 Monmouthshire's urban forest on a single genus

Prevalence	**% of Community**		
	0-25	26-50	>50
Not in UK	🟩	🟧	🟧
Present in UK	🟧	🟧	🟥
Present in Wales	🟧	🟥	🟥

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

Prevalence	**% of Community**		
	0-5	6-10	>10
Not in UK	🟩	🟧	🟧
Present in UK	🟧	🟧	🟥
Present in Wales	🟧	🟥	🟥

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, three *Agrilus* borers, and *Xylella fastidiosa* 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).

Table 12. The significance of a range of existing and emerging pests and diseases to the Monmouthshire study area's urban forest.

Pest / Pathogen / Disease	Major tree species hosts affected	UK Relative Risk Rating Rank[1]	Continued Presence in the UK	Presence in Wales	Risk of spreading to Wales	Urban forest population at risk (%)	CAVAT value of trees[2]
Acute oak decline	*Quercus* spp. including *Q. ilex, petraea, robur*	47	Limited	Especially South	High – already present	**7.4**	£60.7 million
Asian longhorn beetle (*Anoplophora glabripennis*)	Many broadleaf species (see Appendix III)	25	Absent	Absent	Medium – climate change, trade	**60.0**	£349.8 million
Bronze birch borer (*Agrilus anxius*)	*Betula* spp. including *B. pendula, utilis*	12	Absent	Absent	Medium – climate change, trade	**1.4**	£4.7 million
Chalara ash dieback (*Hymenoscyphus fraxineus*)	*Fraxinus* spp.	6	Widespread	Widespread	High – already present	**8.9**	£31.2 million
Dothistroma needle blight (*Dothistroma septosporum*)	*Larix decidua, Pinus spp., Pseudotsuga menziesii*	47	Present	Especially South	High – already present	**1.4**	£4.7 million

Emerald ash borer (*Agrilus planipennis*)	*Fraxinus* spp. including *F. americana, excelsior*	3	Absent	Absent	High – suitable climate, trade	**8.9**	£31.2 million
Oak processionary moth (*Thaumetopoea processionea*)	*Quercus* spp. including *Q. petraea, robur*	12	Limited	Absent	Medium – climate change, trade	**7.4**	£60.7 million
Phytophthora kernoviae	Many broadleaf species (see Appendix III)	12	Limited	Especially South	High – already present	**6.9**	£50.1 million
Ramorum disease (*Phytophthora ramorum*)	Over 150 plants (see Appendix III)	3	Widespread	Widespread	High – already present	**39.5**	£177.4 million
Two-lined chestnut borer (*Agrilus bilineatus*)	*Castanea dentata, Quercus* spp. including *Q. robur*	12	Absent	Absent	Medium – climate change, trade	**7.4**	£60.7 million

1. Rank out of 1240 agents on the UK plant health risk register (assessed October 2021); where the first rank carries the greatest risk, and where there are ties present, the median rank is provided. 2. Rounded to the nearest million.

Net Present Value

The 100yr Present Value (PV) calculated for the Monmouthshire study area's urban forest is £33.7 million, based upon the small proportion of the total value of the ecosystem services that i-Tree Eco can value for an urban forest (Table 13). This value is estimated from only three of the many ecosystem system services urban forests can provide. This value also assumes no change in the urban forest over the next 100 years. The future benefit provision in Monmouthshire will depend both on the demand for services from those who live, work and visit it, but also by how the urban forest will change in the next 100 years. Considering management costs, borne by Monmouthshire CC, of £117,300 annually for maintenance, surveys and replanting, the Net Present Value[1] of Monmouthshire's urban forest is £33.7 million (Table 13). These costs maintain an asset worth £2.4 million (CAVAT value).

Table 13. The total annual value of ecosystem service provision by services Monmouthshire's urban forest and the 100-year Present Value of these services.

Benefit type	Value
Annual costs[2]	£ 117,300
Annual benefits (avoided runoff, air pollution removal, carbon sequestration)	£757,300
Annual net value (benefits minus costs)	£640,000
Benefit: Cost ratio	6.5:1
100-year Present Value (PV) (avoided runoff, air pollution removal and carbon sequetration, discounted)	£33.7 million
100-year Net Present Value (NPV) (avoided runoff and air pollution removal minus costs, discounted)	£30.2 million

1. The Net Present Value (NPV) is the discounted value of benefits over the next 100 years minus the discounted costs over the next 100 years. 2. This value is a cost estimate derived from the Monmouthshire County tree team, back-office support, highways inspection, and framework contractors estimated total spend of £326k per annum and pro rata to the study based upon a calculated 36% of Monmouthshire residential addresses in the study area.

The assumption of no canopy cover change may over-estimate the NPV, considering urban forest cover trends (Doick *et al.* 2020), and continued development pressure in South Wales. However, all considered, the NPV may be an underestimate. First, only air pollution removal, avoided runoff and carbon sequestration are quantified, when there are several more benefits (Tables 1 and 2). Second, Monmouthshire's predicted population growth (Statistics for Wales 2020), is likely to increase the number of individuals benefiting from existing and future urban trees. Third, the value of carbon storage should increase with growth of the forest and the increasing value of carbon.

How the urban forest is managed, both now and in the future, will affect whether current rates of annual benefit provision can be maintained or increased in future years. Ecosystem service provision depends not only on tree planting and removal, but also which species are planted and where, and whether they are maintained in a healthy condition and able to reach maturity. Furthermore, in order to maintain the carbon sequestration values included in this report, substantial levels of tree planting are needed to expand the total carbon storage capacity of the urban forest. If further planting is not undertaken the carbon sequestration rate will slow as the trees reach maturity.

Urban Forest Sustainability

The Monmouthshire study area's urban forest performs well in two of the five urban forest sustainability indicators proposed by Vaz Monteiro *et al*. (2019) (Table 14). Monmouthshire performs fair in canopy cover, as it is between 50 and 75% of the target of 15% cover for coastal towns (Doick *et al*., 2017). Monmouthshire is in the fair category for size diversity according to Richards (1983), because it is skewed towards small trees, with those <20 cm in DBH forming 50 to 60% of the community. Similarly, the study area is good for tree condition being in the band of more than 75% of trees having at least 10% dieback. However, the urban forest is poor with regard to tree diversity with two species, one genus and a family exceeding the 10-20-30% aim. Conversely, it performs well for climate suitability with more than 75% of trees' USDA cold hardiness being appropriate to the location.

Overall, **the urban forest in the Monmouthshire study area is shown to be mid-table for sustainability** (Table 14).

Table 14. Urban forest sustainability rating for Monmouthshire compared to other urban areas in the UK (assessed using the framework of Table 2 in Vaz Monteiro *et al*., 2019).

Region	City / Town	1. Canopy cover	2. Size diversity	3. Taxonomic diversity	4. Tree condition	5. Cold hardiness suitability[1]
Scotland	Edinburgh	🟩	🟥	🟥	🟩	🟩
	Glasgow	🟩	🟥	🟥	🟩	🟩
Wales	Bridgend	🟩	🟥	🟥	🟩	🟩
	Cardiff	🟩	🟩	🟥	🟩	🟩
	Swansea	🟩	🟨	🟥	🟨	🟨
	Wrexham	🟩	🟥	🟥	🟨	🟩
	Newport	🟩	🟩	🟥	🟩	🟩
	Monmouthshire	🟨	🟨	🟥	🟩	🟩
England	Burton	🟥	🟨	🟥	🟩	🟩
	London	🟨	🟨	🟨	🟩	🟩
	Oldham	🟨	🟥	🟥	🟩	🟩
	Petersfield	🟩	🟨	🟥	🟩	🟩
	Southampton	🟩	🟩	🟥	🟥	🟩
	Torbay	🟩	🟥	🟥	🟩	🟩

1. Cold hardiness data available for 99% of trees in Monmouthshire sample.

Conclusions

The urban forest of the Monmouthshire study area is estimated to contain over **80,000 trees**. A total of 60 species were identified in the survey[1]. The three most common tree species are hawthorn, field maple, and ash. When considering tree abundance and leaf area sycamore is the most important. Similarly, the most abundant, and important, genus is maple.

Monmouthshire's urban forest provides **services valued at £757,300 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, amenity value, and biodiversity support. These services can help Monmouthshire CC towards its goals of reducing carbon footprints and improving standards of living.

Monmouthshire's **canopy cover** was estimated to be **10.4[2]%.** Monmouthshire achieves 111th out of the 341 urban locations in rank descending order of canopy cover on the UK webmap. This score is lower than other Welsh coastal urban areas (Doick *et al.*, 2017).

Monmouthshire's forest structure is **unbalanced across taxa**. There is an excess of the hawthorn and field maple species, the maple genus, and the rose family, according to Santamour's (1990) recommendations. 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.

Monmouthshire's tree population is **unbalanced across size classes**. Generally, there is approximately half the number of trees in the two largest size classes, and an excess of small trees (7 - 20 cm DBH), relative to Richard's (1983) guidelines. Cemeteries are an exception, where there is a lack of small trees. Large trees are more effective at ecosystem service delivery, while small trees complement this by increasing diversity and renewing the population of large trees in future.

The **most abundant tree species** in the Monmouthshire study area are **not necessarily the best** for **habitat provision**. For example, 14% of trees are field maple, which only support 43 insect species, whereas English and Irish oaks, despite being 5% of trees, support 423 insect species. Two of the three of the most common tree genera scores high for nectar/pollen and for seeds/fruits.

40% of Monmouthshire’s urban forest had **excellent crown condition**, while **15% were in poor**, or worse, condition. Monmouthshire’s crown condition scores were slightly below average for i-Tree Eco studies.

Asian longhorn beetle, and **Ramorum disease** were identified as the most concerning diseases for Monmouthshire’s urban forest, **10% more of the community would be affected** by them compared two recent like-for-like analyses in England. The assessment was for twenty-seven 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. Ramorum had the highest risk when considering the proportion of Monmouthshire’s tree community which could be affected, and their current establishment around the local area.

The majority of trees **abundance** and species **richness** was in **private ownership**. In the most common public land use, parkland, hawthorn, field maple, and ash were the most abundant species. This contrasts to the most common private land use, residential, where sycamore, apple, then common plum were the most abundant. Residential was also the most diverse land use.

Recommendations

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

Ownership and distribution

Most of Monmouthshire’s tree abundance and richness is found on private land uses such as residential areas. This means that ecosystem services are centred on private land, which restricts direct management of tree diversity, health, renewal, pests, and climate adaptation. Enhancing and reviewing Tree Preservation Orders based on this report, and Educating Monmouthshire’s residents on the significance of this important resource, can be a way to mitigate this risk. For example, exposure to the natural environment was shown to reduce stress, improve memory, decrease rates of depressive disorders and improve mental health survey scores (Alcock *et al*. 2014; Lega *et al*. 2021).

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. 3. Data from December 2021 (Urban Forest Research Group 2022).

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 schemes exist like TreeBristol, and nationally there are disease reporting systems like TreeAlert (Forest Research 2022b). Monmouthshire CC could undertake a detailed evaluation of local land use, enhancing this report’s analysis of the proportional representation of trees on different land uses. Similarly, data could be split by regions to assess the equitability of trees across the population. Greening can be applied to new build developments, where the Woodland Trust suggests LAs 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 *et al.* 2006). A balance of native and non-native species may provide the most resilient solution. In Monmouthshire’s case, it is good that the two most common single species are hawthorn and field maple, which are both native to the UK.

Size demography

Monmouthshire generally has an overabundance of small trees, except in cemeteries where they seem absent. However different land uses have very different DBH profiles. Large trees have been shown to be relatively better for pollution removal, carbon storage, runoff avoidance, and human wellbeing (Wolf *et al.* 2020). However, they need to be replaced by younger trees, due to senescence and death. Considering the risk of diseases (above), and the poor crown conditions (below), the under-representation of large trees may be due to stress and mortality. Monitoring through regular surveys, and/or through a network of sensors, could limit the impact of drought, disease and physical trauma. Under-representation of large trees may also be an artefact of historic planting of small stature trees, or planting trees in areas with limited space for growth. Planting of fast-growing, large-stature, climate-adapted trees, like Oaks should be planted in locations with good scope for growth.

Crown condition and disease risk

Monmouthshire had slightly worse canopy scores compared to previous Welsh i-Tree Eco studies. This may warrant further investigation. First, whether there is a stress from environmental variables like drought, air pollution, or a nutrient deficiency or toxicity in the soil. Second, it there may be a prevalence of different tree diseases. Compared to two similar pest and disease assessments in recent i-Tree Eco studies approximately 10% more of the tree community in Monmouthshire was vulnerable. 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 *et al.* 2019). Forest Research's pest and disease pages, and the UK plant health risk register, provide information on how to monitor, and limit, threats.

Habitat provision

Of the tree species considered, the most abundant taxa in Monmouthshire are not necessarily the best for supporting insects. For example, in Monmouthshire, field maple is seven times more abundant than hazel, but theoretically only supports approximately a quarter of the hazel's species. To improve habitat provision to insects, one may consider planting more willows and oaks instead of maple and hawthorn. Two of the three most common tree genera in Monmouthshire rank relatively high in the provision of nectar/pollen (maples) and seeds/fruits (plums/cherries). Increasing the proportion of apple, lime and rowan may improve food provision. Note that planting cherry/plum and hawthorn would be an efficient use of space as they perform well as supplying multiple feeding guilds across seasons. To maximise habitat provision disease resistant native species should be planted (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).

The Authors

Kris Sales, Hannah Walker, Alexander Chambers-Ostler, Phillip Handley, Chambers-Ostler, A., Kate Sparrow, and Kieron J. Doick of the

Urban Forest Research Group
Centre for Sustainable Forestry and Climate Change
Forest Research
Alice Holt, Surrey
GU10 4LH

Acknowledgements

Our thanks to the USDA Forest Service and the i-Tree Cooperative for their on-going support.

We thank the wonderful Monmouthshire volunteers for conducting the field work.

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

References

Abergavenny Chronicle (2022) Council to Plant New Trees and Wildflowers in Abergavenny Car Park. https://www.abergavennychronicle.com/news/council-to-plant-new-trees-and-wildflowers-in-abergavenny-car-park-543858 (accessed: 08/11/2022).

Alcock I et al. (2014) Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas. Environmental Science and Technology 48, 1247–1255.

Alexander K, Butler J and Green T (2006) The Value of Different Tree and Shrub Species to Wildlife. British Wildlife 18, 18-28.

Ambrose-Oji B et al. (2021) Public Perceptions of Urban Trees. Forest Research Report, Farnham. 1-50

Association of British Insurers (2020) Insurance Pay Outs to Help Customers Recover from Storms Ciara and Dennis Set to Top £360 Million. https://governmentbusiness.co.uk/news/18032020/storm-insurance-pay-outs-top-%C2%A3360-million#:~:text=The%20Association%20of%20British%20Insurers%20has%20said%20that,and%20Dennis%20are%20set%20to%20top%20%C2%A3360%20million (accessed: 08/11/2022).

Baldocchi DD (1988) A Multi-Layer Model for Estimating Sulfur Dioxide Deposition to a Deciduous Oak Forest Canopy. Atmospheric Environment 22, 869–884.

Baldocchi DD, Hicks BB and Camara P (1987) A Canopy Stomatal Resistance Model for Gaseous Deposition to Vegetated Surfaces. Atmospheric Environment 21, 91.

Baldock KCR et al. (2015) Where Is the UK's Pollinator Biodiversity? The Importance of Urban Areas for Flower-Visiting Insects. Proceedings of the Royal Society B: Biological Sciences 282, 20142849.

Begon M, Townsend CR and Harper JL (2006) Ecology: From Individuals to Ecosystems, 4th ed. Wiley-Blackwell, Chichester. 1-750.

Bidwell RGS and Fraser DE (1972) Carbon Monoxide Uptake and Metabolism by Leaves. Canadian Journal of Botany 50, 1435–1439.

Birchby D et al. (2020) Air Quality Damage Cost Update 2020. A Report for DEFRA. Didcot. 1-53.

Booth DB, Hartley D and Jackson R (2002) Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts. Journal of the American Water Resources Association 38, 835–845.

Buckland A et al. (2020) Valuing Newport' s Urban Trees. Forest Research Report, Farnham. 1-67.

Buras A and Menzel A (2019) Projecting Tree Species Composition Changes of European Forests for 2061–2090 under RCP 4.5 and RCP 8.5 Scenarios. Frontiers in Plant Science 9, 1–13.

Burns DA et al. (2016) Acid Rain and Its Environmental Effects: Recent Scientific Advances. Atmospheric Environment 146, 1-4.

Carr A et al. (2018) Ground-Based and LiDAR-Derived Measurements Reveal Scale-Dependent Selection of Roost Characteristics by the Rare Tree-Dwelling Bat *Barbastella barbastellus*. Forest Ecology and Management 417, 237–246.

Chambers-Oster, A. Doick, K. 2021. The Benefits of an i-Tree Eco survey. Forest Research Report, Farnham. 1-4.

Chartered Institute of Environmental Health (2020) CIEH Noise Survey 2019/20 Report on Findings – Wales. CIEH, London.

CIRIA, 2007. The SuDS manual (C753)

https://www.ciria.org/CIRIA/Memberships/The_SuDS_Manual_C753_Chapters.aspx (accessed: 08/11/2022).

Connor EF et al. (1980) Taxonomic Isolation and the Accumulation of Herbivorous Insects: A Comparison of Introduced and Native Trees. Ecological Entomology 5, 205–211.

Council of Tree and Landscape Appraisers (1992) Guide for Plant Appraisal. International Society of Arboriculture, Savoy.

Davies HJ et al. (2017) Delivery of Ecosystem Services by Urban Forests. Forest Research Report, Edinburgh.

DBEIS (2021) Valuation of Greenhouse Gas Emissions: For Policy Appraisal and Evaluation. Policy paper. https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation (accessed: 08/11/2022).

DEFRA (2022a) Chalara (*Hymenoscyphus Fraxineus*) - Infections Confirmed in the Wider Environment. https://chalaramap.fera.co.uk/ (accessed: 08/11/2022).

DEFRA (2010) IGCB Air Quality Damage Costs per Tonne, 2010 Prices. www.defra.gov.uk/environment/quality/air/air-quality/economic/damage/ (accessed: 08/11/2022).

DEFRA (2021) Nature for People, Climate and Wildlife. Policy paper. https://www.gov.uk/government/publications/nature-for-people-climate-and-wildlife/nature-for-people-climate-and-wildlife (accessed: 08/11/2022).

DEFRA (2022b) UK Plant Health Risk Register. https://secure.fera.defra.gov.uk/phiw/riskRegister/index.cfm (accessed: 08/11/2022).

DEFRA (2018) Urban Tree Manual. https://cdn.forestresearch.gov.uk/2022/02/7111_fc_urban_tree_manual_v15.pdf (accessed: 08/11/2022).

Deilami K, Kamruzzaman M and Liu Y (2018) Urban Heat Island Effect: A Systematic Review of Spatio-Temporal Factors, Data, Methods, and Mitigation Measures. International Journal of Applied Earth Observation and Geoinformation 67, 30–42.

Department for Transport (2013) National Travel Survey. 1-25.

Department for Transport (2015) New Car Carbon Dioxide Emissions. Environment Transparency Data. https://www.gov.uk/government/publications/new-car-carbon-dioxide-emissions (accessed: 08/11/2022).

Doick KJ et al. (2018) CAVAT (Capital Asset Value for Amenity Trees): Valuing Amenity Trees as Public Assets. Arboricultural Journal 1–25. https://doi.org/10.1080/03071375.2018.1454077

Doick KJ et al. (2016) Introducing England's Urban Forests.

Doick KJ et al. (2017) The Canopy Cover of England's Towns and Cities: Baselining and Setting Targets to Improve Human Health and Well-Being. Conference Proceedings of TPBEIII. Urban Trees Research Conference. Edinburgh: Institute of Chartered Foresters.

Doick KJ, Buckland A and Clarke TK (2020) Historic Urban Tree Canopy Cover of Great Britain. Forests 11, 1–16.

Duh J Der et al. (2008) Rates of Urbanisation and the Resiliency of Air and Water Quality. Science of the Total Environment 400, 238–256.

East Midlands Councils (2015) The Changing Nature of Flooding in the East Midlands. East Midlands Councils, Melton Mowbray.

Escobedo FJ et al. (2008) Analyzing the Cost Effectiveness of Santiago, Chile's Policy of Using Urban Forests to Improve Air Quality. Journal of Environmental Management 86, 148–157.

Fenoglio MS et al. (2021) Urbanisation Drivers and Underlying Mechanisms of Terrestrial Insect Diversity Loss in Cities. Ecological Entomology 46, 757–771.

Forest Research (2022a) Acute Oak Decline (AOD): Incidence and Distribution. https://www.forestresearch.gov.uk/tools-and-resources/fthr/pest-and-disease-resources/acute-oak-decline/acute-oak-decline-aod-incidence-and-distribution/ (accessed: 08/11/2022).

Forest Research (2022b) TreeAlert. Resources. https://www.forestresearch.gov.uk/tools-and-resources/fthr/tree-alert/ (accessed: 08/11/2022).

Forest Research (2022) Pest and Disease Resources. https://www.forestresearch.gov.uk/tools-and-resources/fthr/pest-and-disease-resources/ (accessed: 08/11/2022).

Forestry Commission (2017) Public Opinion of Forestry - Wales. Edinburgh.

Forestry Commission (2019) Urban Tree Challenge Fund. Guidance. https://www.gov.uk/guidance/urban-tree-challenge-fund (accessed: 08/11/2022).

Greater London Authority (2006) London's Urban Heat Island: A Summary for Decision Makers. Greater London Authority, London.

Hallmann CA et al. (2017) More than 75 Percent Decline over 27 Years in Total Flying Insect Biomass in Protected Areas. PLoS ONE 12, e0185809.

Hand K et al. (2018) Valuing Cardiff's Urban Trees. A Report to City of Cardiff Council and Welsh Government. Forest Research Report, Farnham. 1-95.

Hand KL, Doick KJ and Moss JL (2019) Modelling the Delivery of Regulating Ecosystem Services for Large Stature Trees in the Urban Environment with I-Tree Eco. Forestry Commission, Edinburgh.

Hill JK et al. (2008) Impacts of Landscape Structure on Butterfly Range Expansion. Ecology Letters 4, 313–321.

Hirabayashi S (2013) I-Tree Eco Precipitation Interception Model Descriptions. Davey Tree Expert Company, New York, USA. 1-19.

i-Tree (2021) I-Tree Eco Field Guide. USDA Forest Service, Washington.

Intergovernmental Panel on Climate Change (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva. 1-151.

Jacob DJ and Winner DA (2009) Effect of Climate Change on Air Quality. Atmospheric Environment 43, 51–63.

Johnson O and More D (2006) Collins Tree Guide, 2nd ed. HarperCollins Publishers, London. 1-464.

Kendle AD and Rose JE (2000) The Aliens Have Landed! What Are the Justifications for "Native Only" Policies in Landscape Plantings? Landscape and Urban Planning 47, 19–31.

Kennedy CEJ and Southwood TRE (1984) The Number of Species of Insects Associated with British Trees: A Re-Analysis. The Journal of Animal Ecology 53, 455.

Kew Royal Botanic Gardens (2017) State of the World's Plants 2017. Kew Royal Botanic Gardens, London. 1-445.

Kirby KR and Potvin C (2007) Variation in Carbon Storage among Tree Species: Implications for the Management of a Small-Scale Carbon Sink Project. Forest Ecology and Management 246, 208–221.

Kondo MC et al. (2018) Urban Green Space and Its Impact on Human Health. International Journal of Environmental Research and Public Health 15, 445.

Landry J-S et al. (2016) Modelling Long-Term Impacts of Mountain Pine Beetle Outbreaks on Merchantable Biomass, Ecosystem Carbon, Albedo, and Radiative Forcing. Biogeosciences 13, 5277–5295.

Larner J, Rynne C and McLaughlin M (1992) The Oakwoods of Killarney. Government Publications, Dublin. 1-48.

Lee JD et al. (2006) Ozone Photochemistry and Elevated Isoprene during the UK Heatwave of August 2003. Atmospheric Environment 40, 7598–7613.

Lega C et al. (2021) The Relationship between Surrounding Greenness, Stress and Memory. Urban Forestry & Urban Greening 59, 126974.

Lin BS and Lin YJ (2010) Cooling Effect of Shade Trees with Different Characteristics in a Subtropical Urban Park. HortScience 45, 83–86.

Lovett GM (1994) Atmospheric Deposition of Nutrients and Pollutants in North America: An Ecological Perspective. Ecological Applications 4, 629–650.

MacLeod A, Evans H. and Baker RH. (2002) An Analysis of Pest Risk from an Asian Longhorn Beetle (*Anoplophora Glabripennis*) to Hardwood Trees in the European Community. Crop Protection 21, 635–645.

Manisalidis I et al. (2020) Environmental and Health Impacts of Air Pollution: A Review. Frontiers in Public Health 8, 1–13.

Millennium Ecosystem Assessment Board (2005) Ecosystems and Human Well-Being: Synthesis. World Health Organisation, Geneva.

Miller JR (2005) Biodiversity Conservation and the Extinction of Experience. Trends in ecology & evolution 20, 430–434.

Mitchell CE and Power AO (2003) Release of Invasive Plants from Fungal and Viral Pathogens. Nature 421, 625–627.

Mitchell RJ et al. (2019) Collapsing Foundations: The Ecology of the British Oak, Implications of Its Decline and Mitigation Options. Biological Conservation 233, 316–327.

Monmouthshire County Council (2022a) New Trees Planted in Bailey Park to Improve Green Infrastructure. https://www.monmouthshire.gov.uk/2022/03/new-trees-planted-in-bailey-park-to-improve-green-infrastructure/ (accessed: 08/11/2022).

Monmouthshire County Council (2022) Air Quality Management Areas. Air Quality. https://www.monmouthshire.gov.uk/air-quality/ (accessed: 08/11/2022).

Monmouthshire County Council (2021) Climate Emergency Strategy and Action Plan. Monmouthshire CC, Usk. 1-11.

Monmouthshire County Council (2020a) Growth and Spatial Options Paper. Monmouthshire CC, Usk. 1-192.

Monmouthshire County Council (2020b) Help Make Monmouth’s Catalpa ‘Tree of the Year 2020’. News. https://www.monmouthshire.gov.uk/2020/08/help-make-monmouths-catalpa-tree-of-the-year-2020/ (accessed: 08/11/2022).

Monmouthshire County Council (2018) Interactive Local Development Plan Map. https://www.monmouthshire.gov.uk/planning-policy/interactive-local-development-plan-mapping/ (accessed: 08/11/2022).

Monmouthshire County Council (2020c) Monmouthshire Replacement Local Development Plan. Monmouthshire CC, Usk. 1-192.

Moss JL et al. (2019) Influence of Evaporative Cooling by Urban Forests on Cooling Demand in Cities. Urban Forestry and Urban Greening 37, 65–73.

Mullett M (2014) The Epidemiology of *Dothistroma* Needle Blight in Britain. PhD Thesis, Imperial College. 1-269.

Murphy JM et al. (2009) UK Climate Projections Science Report: Climate Change Projections. Meteorological Office Hadley Centre, Exeter. 1-192

National Ecosystem Assessment (2014) The UK National Ecosystem Assessment Follow-on: Synthesis of the Key Findings. Cambridge.

Natural Capital Committee (2014) Towards a Framework for Defining and Measuring Changes in Natural Capital. London.

Natural Resources Wales (2020) February 2020 Floods in Wales: Flood Event Data Summary. NRW, Cardiff. 1-42.

Natural Resources Wales (2021) Find Protected Areas of Land and Sea. https://naturalresources.wales/guidance-and-advice/environmental-topics/wildlife-and-biodiversity/protected-areas-of-land-and-seas/find-protected-areas-of-land-and-sea/?lang=en (accessed: 08/11/2022).

Natural Resources Wales (2016) Welsh Outdoor Recreation Survey – Key Facts for Policy and Practice: Summary Report. NRW, Cardiff. 1-22.

Nghiem TPL et al. (2021) Biodiverse Urban Forests, Happy People: Experimental Evidence Linking Perceived Biodiversity, Restoration, and Emotional Wellbeing. Urban Forestry and Urban Greening 59, 1–8.

NHS/Department of Health (2008) Heatwave Plan for England. Protecting Health and Reducing Harm from Extreme Heat and Heatwaves. NHS/Department of Health, London.

Nielsen AB et al. (2014) Species Richness in Urban Parks and Its Drivers: A Review of Empirical Evidence. Urban Ecosystems 17, 305–327.

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

Nowak DJ et al. (2008) A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services. Arboriculture & Urban Forestry 34, 347–358.

Nowak DJ (1995) Trees Pollute? A 'TREE' Explains It All. Proceedings of the 7th National Urban Forestry Conference. Washington: American Forests, pp. 28–30.

Nowak DJ, Crane DE and Stevens JC (2006) Air Pollution Removal by Urban Trees and Shrubs in the United States. Urban Forestry & Urban Greening 4, 115–123.

O'Sullivan OS et al. (2017) Optimising UK Urban Road Verge Contributions to Biodiversity and Ecosystem Services with Cost-Effective Management. Journal of Environmental Management 191, 162–171.

Oliver T et al. (2015) Declining Resilience of Ecosystem Functions under Biodiversity Loss. Nat Commun 6, 10122.

Ozdemiroglu E et al. (2013) Green Infrastructure – Valuation Tools Assessment, NECR126 ed. Natural England.

Palmer J and Cooper I (2013) Great Britain's Housing Energy Fact File 2013. London.

Parmesan C et al. (2015) Endangered Quino Checkerspot Butterfly and Climate Change: Short-Term Success but Long-Term Vulnerability? Journal of Insect Conservation 22, 185–204.

Poland TM and McCullough DG (2006) Emerald Ash Borer: Invasion of the Urban Forest and the Threat to North America's Ash Resource. Journal of Forestry 104, 118–124.

Public Health England (2019) Review of Interventions to Improve Outdoor Air Quality and Public Health. PHE, London. 1-262.

Reid C et al. (2021) State of the UK's Woods and Trees. Woodland Trust, Grantham. 1-244.

Richards NA (1983) Diversity and Stability in a Street Tree Population. Urban Ecology 7, 159–171.

Rivers M et al. (2019) European red list of trees. International Union for Conservation of Nature and Natural Resources (IUCN).

Rogers K et al. (2015) Valuing London's Urban Forest - Results of the London i-Tree Eco Project. Treeconomics, Exeter. 1-80.

Royal Horticultural Society (2018) RHS Plants for Pollinators. Advice. https://www.rhs.org.uk/science/conservation-biodiversity/wildlife/encourage-wildlife-to-your-garden/plants-for-pollinators (accessed: 08/11/2022).

Royal Horticultural Society (2021) Trees for Climate Change. Advice. https://www.rhs.org.uk/plants/types/trees/for-climate-change (accessed: 08/11/2022).

Rumble H et al. (2015) Valuing Wrexham's Urban Forest - Assessing the Ecosystem Services of Wrexham's Urban Trees: A Technical Report. Forest Research Report, Farnham. 1-54.

Rundel PW, Dickie IA and Richardson DM (2014) Tree Invasions into Treeless Areas: Mechanisms and Ecosystem Processes. Biological Invasions 16, 663–675.

Sales K, Gardner J and Kerr L (2016) Factors Influencing Epiphytic Moss and Lichen Distribution within Killarney National Park. Bioscience Horizons 9, hzw008.

Santamour FS (1990) Trees for Urban Planting: Diversity, Uniformity and Common Sense. Proceedings of the Conference Metropolitan Tree Improvement Alliance (METRIA). pp. 57–65.

Sefton C et al. (2021) The 2019/2020 Floods in the UK: A Hydrological Appraisal. Weather 76, 378–384.

Seibold S et al. (2015) Experimental Studies of Dead-Wood Biodiversity - A Review Identifying Global Gaps in Knowledge. Biological Conservation 191, 139–149.

Seitz J and Escobedo F (2011) Urban Forests in Florida : Trees Control Stormwater Runoff and Improve Water Quality 1 How Do Trees Affect the Water. Journal Of Arboriculture 1–4.

Sjöman H et al. (2016) Diversification of the Urban Forest—Can We Afford to Exclude Exotic Tree Species? Urban Forestry & Urban Greening 18, 237–241.

Smith IA, Dearborn VK and Hutyra LR (2019) Live Fast, Die Young: Accelerated Growth, Mortality, and Turnover in Street Trees. PLoS ONE 14, e0215846.

Smith RM et al. (2006) Urban Domestic Gardens (VIII): Environmental Correlates of Invertebrate Abundance. Biodiversity & Conservation 15, 2515–2545.

Southwood TRE (1961) The Number of Species of Insect Associated with Various Trees. The Journal of Animal Ecology 30, 1–8.

Statistics for Wales (2014) Local Area Summary Statistics. Welsh Government, Cardiff. 1-47.

Statistics for Wales (2020) Local Authority Population Projections for Wales: 2018-Based (Revised). Welsh Government and ONS, Newport. 1-25.

Straw NA et al. (2013) Distribution, Impact and Rate of Spread of Emerald Ash Borer Agrilus Planipennis (Coleoptera: Buprestidae) in the Moscow Region of Russia. Forestry 86, 515–522.

Straw NA et al. (2016) History and Development of an Isolated Outbreak of Asian Longhorn Beetle Anoplophora Glabripennis (Coleoptera: Cerambycidae) in Southern England. Agric. For. Entomol. 18, 280–293.

Thomas CD et al. (2004) Extinction Risk from Climate Change. Nature 427, 145–148.

Twigger-Ross C (2005) The Impact of Flooding on Urban and Rural Communities: R&D Technical Report. Environment Agency & DEFRA, Bristol. 1-45.

Urban Forest Research Group (2022) UK Urban Canopy Cover. Forest Research. https://www.forestresearch.gov.uk/research/i-tree-eco/urbancanopycover/ (accessed: 08/11/2022).

Vaz Monteiro M, Handley P and Doick KJ (2019) An Insight to the Current State and Sustainability of Urban Forests across Great Britain Based on i-Tree Eco Surveys. Forestry 93, 107–123.

Visit Monmouthshire (2022) Facts about Monmouthshire. https://www.visitmonmouthshire.com/information/events-management/facts-about-monmouthshire (accessed: 08/11/2022).

Wainhouse D and Inward DJG (2016) The Effects of Climate Change on Invasive Insect Pests in the UK. Forest Research Report, Farnham. 1-10.

Webber J (2010) Dutch Elm Disease – Q&A. Forest Research Pathology Advisory Note No. 10. Forest Research Report, Farnham.

Welsh Government (2021) Population Estimates by Local Authority and Year. StatsWales. https://statswales.gov.wales/Catalogue/Population-and-Migration/Population/Estimates/Local-Authority/populationestimates-by-localauthority-year (accessed: 08/11/2022).

Welsh Government (2020) Road Traffic: 2020. Statistics and Research. https://gov.wales/road-traffic-2020-html (accessed: 08/11/2022).

Welsh Water (2021) Scheme of Our Charges 2020-21. WW, Cardiff.

Wolf K. et al. (2020) Urban Trees and Human Health: A Scoping Review. International Journal of Environmental Research and Public Health 17, 4371.

Woodland Trust (2022) Ancient Tree Inventory. https://ati.woodlandtrust.org.uk/ (accessed: 08/11/2022).

World Resources Institute (2022) Rates of Forest Change in Monmouthshire, Wales, United Kingdom. Global Forest Watch. https://www.globalforestwatch.org/dashboards/ (accessed: 08/11/2022).

Zhou Y, Varquez ACG and Kanda M (2019) High-Resolution Global Urban Growth Projection Based on Multiple Applications of the SLEUTH Urban Growth Model. Scientific Data 6, 1–10.

Zinke PJ (1967) Forest Interception Studies in the United States. In Sopper WE and Lull HW (eds), Forest Hydrology. Oxford: Pergamon Press, pp. 137–161.

Appendix I - Detailed Methodology

i-Tree Eco Models and Field Measurements

i-Tree Eco is designed to use standardised field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak *et al.* 2008), including:

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

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

Table 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 £1.47 of waste water to public sewer, set by the Welsh Water 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 *et al.* 1987; Baldocchi 1988). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell & Fraser 1972; Lovett 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50% re-suspension rate of particles (Zinke 1967).

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

Replacement costs: are based on valuation procedures of the 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 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 at 100%. In actuality therefore, the survey concentrated on accessibility, functionality, appropriateness and SLE.

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

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

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

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

Appendix II - Species Importance List

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 maple	6.60	16.00	22.60
Hawthorn spp.	16.90	4.60	21.60
Hedge maple	14.30	6.80	21.10
Lime spp.	1.70	16.60	18.30
Ash spp.	8.90	8.60	17.40
Sweet cherry	6.60	3.50	10.10
English oak	4.30	4.70	9.00
Horse chestnut	1.10	7.10	8.30
Lombardy poplar	1.70	3.80	5.50
White willow	0.60	3.30	3.90
Port orford cedar	1.40	2.10	3.60
Goat willow	2.00	1.10	3.20
Austrian pine	0.30	2.80	3.10
Irish oak	0.60	2.10	2.70
Holly oak	1.10	1.40	2.50
English walnut	0.30	2.20	2.50
European white birch	1.40	0.80	2.30
Common hazel	1.70	0.40	2.10
Western redcedar	0.30	1.80	2.00
Oak spp.	1.40	0.50	1.90
Douglas fir	0.90	0.90	1.70
European beech	0.60	1.10	1.60
Willow spp.	1.40	0.20	1.60
Monkeypuzzle tree	0.30	1.30	1.60
Apple spp.	1.40	0.10	1.50
Mountain ash spp.	1.10	0.30	1.40
European larch	0.30	1.00	1.30
Common plum	1.10	0.10	1.20
Red horsechestnut	0.30	0.80	1.00
Golden weeping Willow	0.30	0.70	1.00
European mountain ash	0.90	0.20	1.00

English elm	0.90	0.10	0.90
Giant dracaena	0.90	0.00	0.90
Leyland cypress	0.90	0.00	0.90
Black locust	0.60	0.20	0.80
Magnolia spp.	0.60	0.20	0.80
Crack willow	0.60	0.20	0.80
Hazelnut spp.	0.60	0.20	0.80
Grey alder	0.60	0.20	0.80
Cheesewood spp.	0.60	0.10	0.70
European bird cherry	0.60	0.10	0.70
Cypress spp.	0.60	0.10	0.70
European elder	0.60	0.10	0.60
Kanzan cherry	0.60	0.10	0.60
Japanese maple	0.60	0.10	0.60
English holly	0.30	0.30	0.60
False cypress spp.	0.30	0.30	0.60
Bloodtwig dogwood	0.60	0.00	0.60
Plum spp.	0.60	0.00	0.60
Common fig	0.30	0.10	0.40
Wych elm	0.30	0.10	0.40
Chonosuki crabapple	0.30	0.10	0.40
Paradise apple	0.30	0.10	0.40
Italian cypress	0.30	0.10	0.40
Elder spp.	0.30	0.10	0.40
Northern white cedar	0.30	0.10	0.40
Ginkgo spp.	0.30	0.00	0.30
Bay tree spp.	0.30	0.00	0.30
Portugal laurel	0.30	0.00	0.30
Llilac spp.	0.30	0.00	0.30
Norway maple	0.30	0.00	0.30
Cherry laurel	0.30	0.00	0.30
Monterey cypress	0.30	0.00	0.30
Apricot	0.30	0.00	0.30
Spindle	0.30	0.00	0.30
Serviceberry spp.	0.30	0.00	0.30
Japanese flowering cherry	0.30	0.00	0.30
Bay laurel	0.30	0.00	0.30
Holly spp.	0.30	0.00	0.30

European hornbeam	0.30	0.00	0.30
Golden chain tree	0.30	0.00	0.30
Moundlily yucca	0.30	0.00	0.30
Cherry plum	0.30	0.00	0.30
Sycamore spp.	0.30	0.00	0.30
Golden-chain tree	0.30	0.00	0.30

Appendix III – Pests and Diseases

Acute oak decline

Acute oak decline (AOD) affects mature trees (>50 years old) of both native oak species (English oak and Irish 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. It has been recorded along the Severn Estuary, such as in Newport. Predictive modelling which considers temperature, rainfall and nitrogen air pollution suggest Monmouthshire 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.

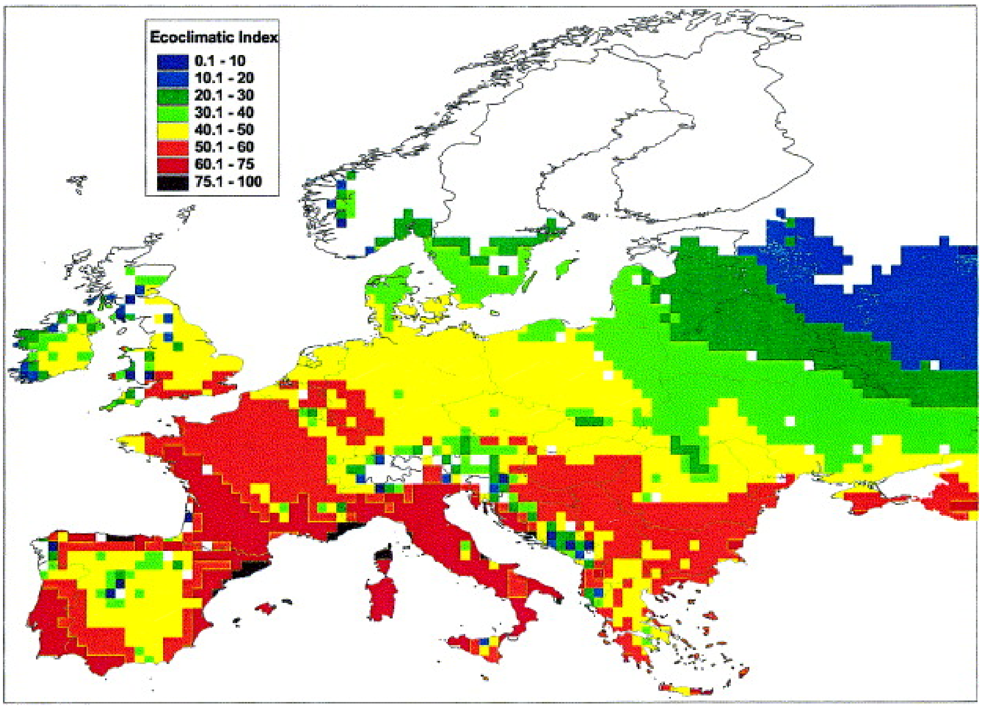


Figure A. Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB (MacLeod *et al.*, 2002).

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 Monmouthshire 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)

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.

Chalara dieback of ash

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 can 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 with concentrations in the South, East and North West. (DEFRA 2022a). Since 2016 it has been present in nearly every 10 km grid square mapped onto Wales, and was first noticed in Monmouthshire in 2018. Coastline 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.

Dothistroma needle blight (*Dothistroma septosporum*)

This is a fungus which targets conifers, particularly pines. Symptoms present as a red-brown banding of leaves, which are lost within weeks. Spores are spread leaves via wind. In Wales, there have been repeated outbreaks since 1958, and in the UK it is widespread with 70% Corsican pines (*Pinus nigra*) affected (Mullett 2014). Originally it impacted southern hemisphere, but has spread across Europe, North America and China recently.

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 & 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.

Phytophthora kernoviae

Phytophthora kernoviae, a species of water mould, was first discovered in Cornwall in 2003. It is concentrated in the South West and by 2010 it was recorded in South Wales. 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. [Distribution of Phytophthora kernoviae - Forest Research]

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)

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 this beetle 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.

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 2010, 10 km grid squares across South Wales were one of the first locations where Ramorum was identified, the region is now a disease management zone [Pr_Outbreak_map_at_Feb_2020.pdf (forestresearch.gov.uk)]

Tree host species include:

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

Appendix IV - 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 habitat, 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 Monmouthshire County 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 in a series of numbers 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,

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.

Alice Holt Lodge
Farnham
Surrey, GU10 4LH, UK
Tel: **0300 067 5600**

Northern Research Station
Roslin
Midlothian, EH25 9SY, UK
Tel: **0300 067 5900**

Forest Research in Wales
Environment Centre Wales
Deiniol Road, Bangor
Gwynedd, LL57 2UW, UK
Tel: **0300 067 5774**

info@forestresearch.gov.uk
www.forestresearch.gov.uk

Forest Research will consider all requests to make the content of our documents available in alternative formats.

Please send any such requests to: research.info@forestresearch.gov.uk