VALUING BELFAST'S URBAN FOREST

Belfast City Council

Project Funding & Support

Project Support:

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Executive Summary

The urban forest of Belfast is a vital resource for the city. It provides a number of benefits to the residents, and the ecosystem services reported here are just a few of them. This study captures an immediate snapshot of the urban forest at the present time in relation to the plots sampled. It does not consider how the urban forest has or might change over time, or the reasons for this change. Its purpose is to provide a means to make informed decisions on how the urban forest could and should change in the future, and how to ensure that it is healthy and resilient.

- i-Tree Eco estimates that there are over 808,000 trees in Belfast. Tree cover in Belfast stands at an estimated 14.5% and shrub cover at an estimated 8.6%, making up a total canopy cover of 23% of Belfast covering 3,080 hectares.

- These trees have the potential to trap and remove over 210 tonnes of air pollution annually at a value of nearly £7.5 million. These pollutants include ozone (O_3), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2).

- These trees reduce surface runoff by over 317,000 m^3 per year. This volume is equivalent to 127 Olympic swimming pools of surface runoff being averted every single year, and it is worth an estimated £593,000 in avoided surface runoff treatment costs.

- In total, the 808,000 trees store around 319,000 tonnes of carbon and sequester more than 8,890 tonnes of carbon annually with associated values of around £290,000,000 and £593,000 respectively.

- The average newly registered car in the UK produces 34.3g carbon per km. Carbon sequestration across all sites therefore corresponds to around 25,900,000 'new' vehicle km per year, which is equivalent to 4,950 people driving a car every year.[1]

- Trees also confer many other benefits such as habitat provision, soil conservation and noise reduction which currently cannot be valued, but should be considered. i-Tree Eco recorded 83 different species of tree in Belfast.

- The most common tree species are *Fraxinus excelsior* (ash) with an estimated 26,604 trees, *Acer psuedoplatanus* (sycamore) with an estimated 23,592 trees, and *Fagus sylvatica* (beech) with an estimated 22,600 trees.

- Belfast's urban forest performs well in terms of its structure, with a wide variety of species. There is some dominance of *Fraxinus excelsior* (ash) at a species level, and it is recommended that this is rectified to improve overall resilience considering the risks of ash dieback.

- There is a good distribution of both semi-mature and mature trees, however there are very few large senescent trees. Managing trees to ensure they reach this large stature is important as large trees provide far more benefits than small trees. Also further planting of young trees should be undertaken to support an ageing population.

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/823068/national-travel-survey-2018.pdf (Page 15)

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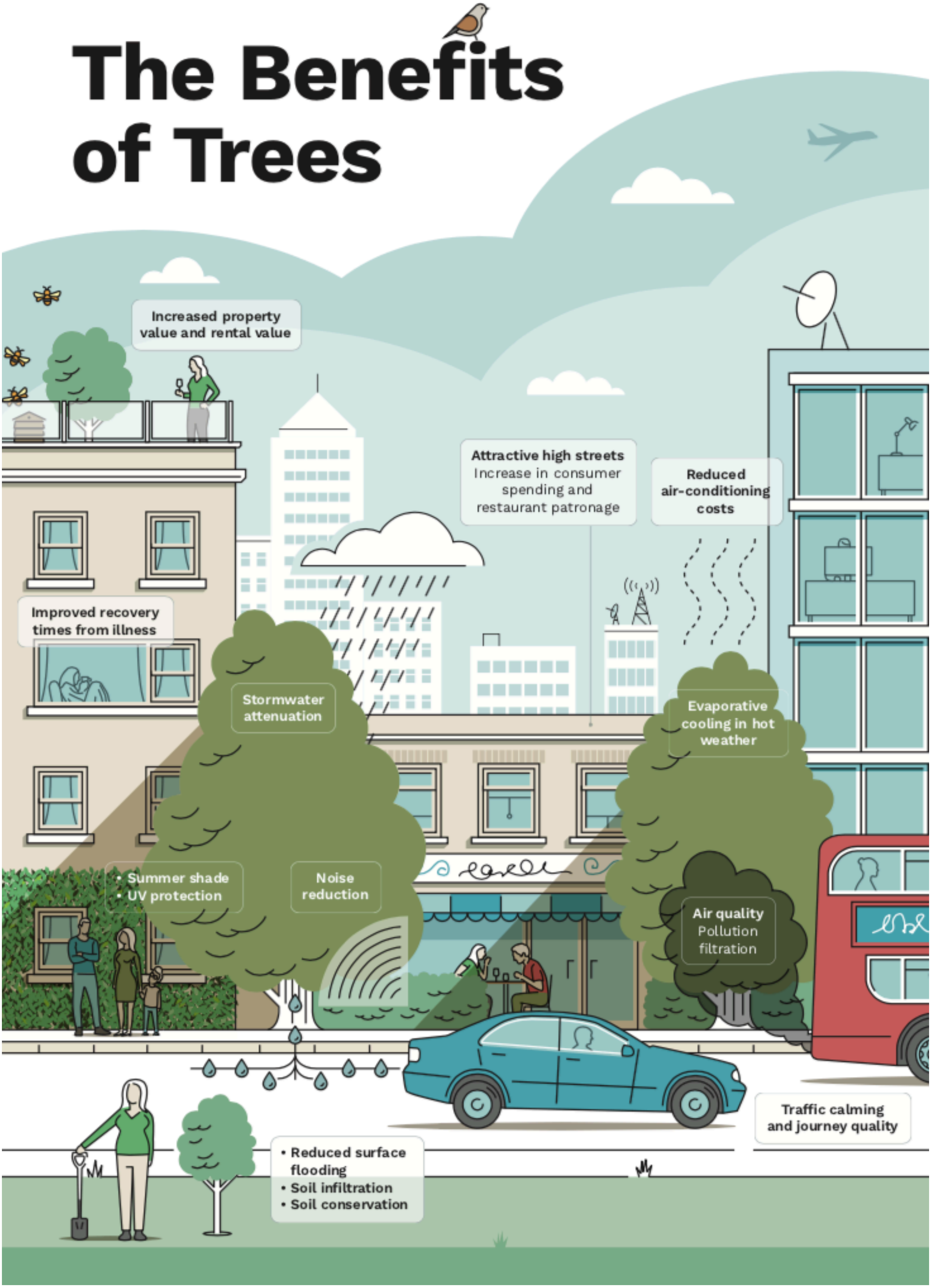
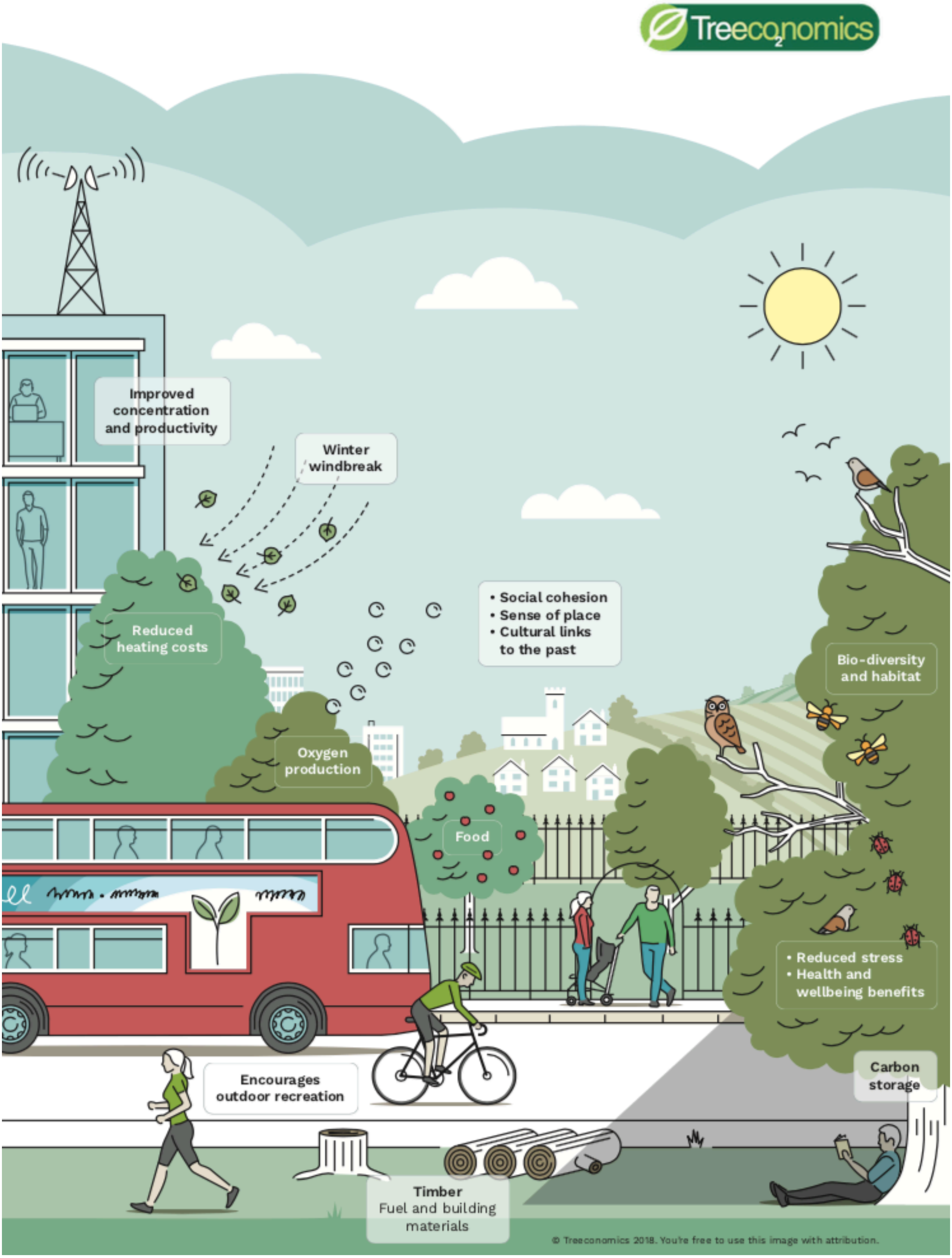
The Benefits of Trees





Treeconomics
Improved concentration and productivity
Winter windbreak
Reduced heating costs
Oxygen production
• Social cohesion
• Sense of place
• Cultural links to the past
Bio-diversity and habitat
Food
• Reduced stress
• Health and wellbeing benefits
Carbon storage
Encourages outdoor recreation
Timber
Fuel and building materials
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Key Definitions

Urban forest: 'all the trees in the urban realm – in public and private spaces, along linear routes and waterways, and in amenity areas. It contributes to green infrastructure and the wider urban ecosystem' (Davies et al., 2017).

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

Natural capital: refers to the elements of the natural environment – such as the trees and shrubs of an urban forest - that provide goods, benefits and services to people, such as clean air, food and opportunities for recreation (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.

Ecosystem services: refers to the benefits which trees provide to the surrounding environment and people. This includes a range of benefits, from urban cooling to amenity value. In this report, the ecosystem services measured are carbon storage and sequestration, pollution removal and avoided surface run-off.

Links

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

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

Report Scope

This study investigates the structure and composition of Belfast's urban forest and the benefits it delivers. The report provides baseline information which can be used to inform future decision making and strategy. Understanding the structure and composition of the urban forest is vital to its preservation and development, and by showcasing the value of benefits provided by Belfast's trees, increased awareness can be used to encourage investment in the wider environment.

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

- Maintaining and improving current tree cover in Belfast
- Identifying areas vulnerable to loss of tree cover (e.g. as a result of pests, diseases, or development) which would benefit from new planting or enhanced protection

This report can be used by:

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

Highlights

Structure and Composition Headline Figures	
Number of Trees (estimate)	**809,000**
Average Tree Density (estimate of trees per hectare)	**61**
Tree Cover	**14.5%**
Shrub Cover	**8.6%**
Total Canopy Cover (Tree + Shrub Cover)	**23.1%**
Number of Species Surveyed	**83**
Most Common Tree Species	***Fraxinus excelsior*- 11.2%** ***Acer pseudoplatanus* - 9.2%** ***Fagus sylvatica* - 5.4%**
Proportion of Trees in Good or Excellent Condition	**35%**
Proportion of Trees by Diameter at Breast Height (DBH)	**0-15 cm - 34%** **15-45 cm - 47%** **45-75 cm - 13%** **75+ cm - 4%**
Replacement Cost	**£973,000,000**
Amenity Value of forest in Urban areas (CAVAT)	**£4,640,000,000**

Ecosystem Services Headline Figures		
Carbon Storage (whole value)	**319,000 tonnes**	**£290,000,000**
Carbon Sequestration (annual)	**8,890 tonnes**	**£8,090,000**
Pollution Removal (annual)	**211 tonnes**	**£7,460,000**
Avoided Runoff (annual)	**317,000 m³**	**£593,000**
Total Annual Benefits	**£16,100,000**	

Table 1: Headline Figures

1. Introduction

Belfast currently has a total tree cover cover of 14.5%, which is just below the average tree cover for England of 16%. Shrub cover contributes an additional 8.6% burning the total canopy cover (including both trees and shrubs) to 23%.

The 2019 mid year estimate for the population of Belfast according to the Belfast Resilience Assessment was 343,542 which was an increase from the most recent census in 2011 which stated there was a population of 288,306 within the Belfast Local Government District. The population is predicted to increase by 5% by 2035. The city has a large student population (est. 24,915) from Queen's University Belfast.

In Belfast 77.3% of the population live within walking distance of a park or play area and approximately 31% of all journeys are taken by either foot or bike. The average number of people using sustainable modes of transport is higher in Belfast than in most other areas in the UK. For comparison, In England, roughly 27% of journeys people take are made by walking or cycling.

Plans for the future of Belfast’s green and blue infrastructure are supported by five strategic principles encouraging all developments to be:

- Biodiverse.
- Part of planned, interconnected networks.
- Integrated into the urban environment.
- Well designed and managed.
- Appropriately funded.

If Belfast is to retain and maintain their leafy heritage there is a well-understood need within Belfast’s planning and policy documents to protect and manage the established trees in the city, whilst continuing to plant the right tree in the right place, as recognised within the Belfast One Million trees campaign.

The Belfast i-Tree Eco project aims to:

1. Illustrate the structure of Belfast's urban forest, including the species composition, diversity, and tree condition.
2. Calculate the ecosystem service values provided by Belfast's urban forest and rank the importance of different trees in terms of ecosystem service (ES) provision using the i-Tree Eco software suite.
3. Promote Belfast's urban forest to all, and emphasise the benefits it provides.
4. Establish values that are a precursor to proper asset and risk management.
5. Conduct a risk analysis of the susceptibility of Belfast's urban forest to pests and diseases.

2. Methodology

To gather a collective representation of Belfast's urban forest across both public and privately held land, an i-Tree Eco (v6) plot-based assessment was undertaken. 312 randomly allocated plots of 0.04ha (400 m^2) were surveyed. This equates to 1 plot every 43 ha.

For comparison with other i-Tree Eco studies, please see Table 2 (below). Random plot selection ensures that trees on both public and private land are included in the assessment.

The data collected for these plots is then extrapolated to represent the whole of the study area.

Study Location	Plots per area
Petersfield	1 plot per 2.7 ha
Cambridge	1 plot per 20.0 ha
Torbay	1 plot per 26.0 ha
Plymouth	1 plot per 28.5 ha
Belfast	1 plot per 43 ha
Inner London	1 plot per 155.0 ha
Outer London	1 plot per 245.0 ha

Table 2: Comparison of plots per area in different study locations.

The following information was recorded for each plot:

Plot Characteristics

Land use, ground cover, % tree cover, % shrub cover, % plantable space, % impermeable surface.

Tree Characteristics

Tree species, shrub species (if known), height (m), trunk diameter at breast height (DBH), canopy spread, the health and fullness of the canopy, light exposure to the crown, distance and direction to the nearest building, life expectancy (LE), tree typology (e.g woodland) and brownfield site identification.

This data was collected by a team of trained contractors during Summer 2021. To ensure enough samples plots were placed in each stratum, a total of 351 random plots were created using GIS software, with 234 in the Urban stratum and 117 in the Rural stratum. Some plots were found to be inaccessible through GIS analysis or in the field, leaving 312 plots that were successfully surveyed.

As the plots were randomly allocated to ensure a statistically significant distribution across Belfast, they fall on both public and private land. While most areas could be accessed with permission, some could not. In the event that the plot landed in an area that was inaccessible, a back-up plot was used. This was a randomly allocated plot within the same grid square as the original which ensured that as many plots as possible were surveyed.

Data Limitations

While Belfast's trees provide a plethora of benefits, the figures presented in this study represent only a portion of the total value of the city's trees. i-Tree Eco does not quantify all of the services that trees provide, such as moderating local air temperatures, reducing noise pollution, improving health and well-being and, even, their ability to unite communities. Hence, the value of the ecosystem services provided in this report are a conservative estimate. Furthermore, the methodology has been devised to provide a statistically reliable representation of Belfast's urban forest in 2021. This report is concerned with the trees and shrubs within Belfast. This report should be used only for generalised information on the urban forest structure, function, and value. Where detailed information for a specific area (such as an individual park, street or ward) is required, further detailed survey work should be carried out.

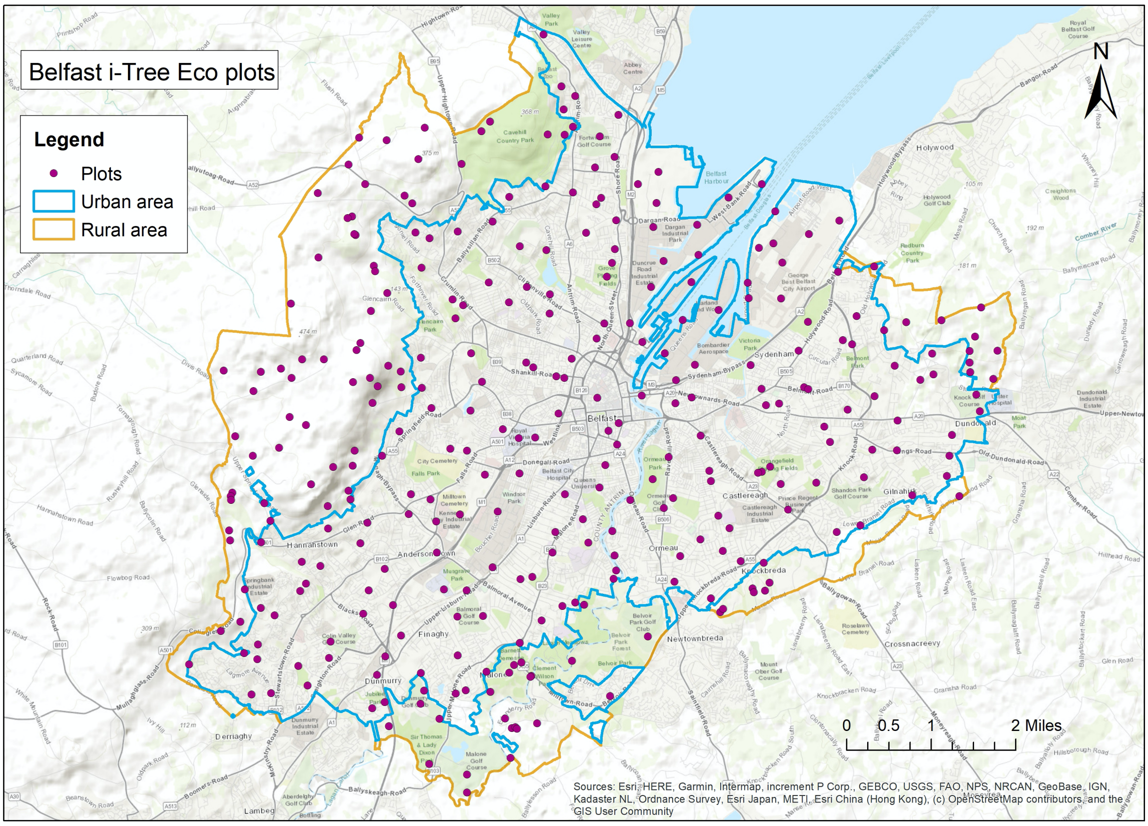

FIgure 1. Sample Plot Distribution Across Study Area

Data was processed using iTree Eco Version 6.0.21.

	Reference Values & Methodology Notes for Calculations
Number of Trees	The sample inventory figures are estimated by extrapolation from the sample plots. For further details see the methodology section below.
Total Canopy Cover	The area of ground covered by the leaves of trees and shrubs when viewed from above (not to be confused with leaf area which is the total surface area of leaves).
Capital Asset Value for Amenity Trees (CAVAT)	A valuation method with a similar basis to the CTLA Trunk Formula Method, but one developed in the UK to express a tree's relative contribution to public amenity value.
Replacement Cost	The cost of having to replace a tree with a similar tree using the Council of Tree and Landscape Appraisers (CTLA) Methodology guidance from the Royal Institute of Chartered Surveyors.
Carbon Storage	The amount of carbon bound up in the above-ground and below-ground parts of woody vegetation.
Carbon Sequestration	The annual removal of carbon dioxide from the air by plants. Carbon storage and carbon sequestration values are calculated based on BEIS figures of £248 per tonne for 2022.
Pollution Removal	This value is calculated based on the UK social damage costs for 'Transport Urban Medium' and the US externality prices where UK figures are not available: £0.96 per kg (carbon monoxide - USEC), £22.27 per kg (ozone - USEC), £14.57 per kg (nitrogen dioxide - UKSDC), £6.92 per kg (sulphur dioxide - UKSDC), £276.264 per kg (particulate matter less than 2.5 microns - UKSDC). Values calculated using an exchange rate of $0.75 = £1.00.
Avoided Runoff	Based on the amount of water held in the tree canopy and re-evaporated after the rainfall event, the amount of infiltration into soil and transpiration. The value is based on an average volumetric charge of £1.868 per cubic metre and includes the cost of avoided energy and associated greenhouse gas emissions. Costed as per Northern Ireland Water charges for surface water and sewerage 2021/22 figures; https://www.niwater.com/sitefiles/resources/news/2021/march/niwsummaryofchargesleaflet21_22.pdf
Total Annual Benefits	Sum of the monetary values of carbon sequestration, pollution removal and avoided runoff. Carbon storage is not included since it is not an annual benefit, but rather a static value of the current carbon storage by the urban forest, which has accumulated over time to the present day.

Table 3: Calculations Summary

3. Results

This chapter presents the results of Belfast's i-Tree Eco survey. Throughout, comparisons of results are drawn from these previous UK i-Tree Eco study reports:

	Belfast	Cambridge	Newport	Torbay	London
Units of canopy cover (ha)	3,080	540	582	765	22,326
Plot Density	1 per 43 ha	1 per 20 ha	1 per 24 ha	1 per 26 ha	1 per 221 ha
Carbon Storage per unit of canopy	103 tonnes	163 tonnes	130 tonnes	128 tonnes	106 tonnes
Carbon Sequestrat-ion per unit of canopy	2.9 tonnes	3.8 tonnes	3.6 tonnes	4.3 tonnes	3.5 tonnes
Pollution Removal per unit of canopy	69 kilograms	119 kilograms	130 kilograms	65 kilograms	100 kilograms
Avoided Runoff per unit of canopy	103 m^3	181 m^3	151 m^3	-	153 m^3

Table 4: Outputs from Belfast's i-Tree Eco Study compared with four other cities

Policy Context

The structure of the urban forest is vital to maintaining and enhancing biodiversity within cities. Diverse forests provide habitats for a greater range of insects, birds, mammals, and other creatures. It also promotes healthier soil, populations and landscapes, less at risk from pests and disease. For these reasons, biodiversity is a major focus of many polices at international and national level, and encouraging biodiversity net gain in urban development is becoming an increasing priority.

The 2030 Agenda for Sustainable Development, is an action plan with the aim of achieving global sustainability by encouraging member states to further progress the economic, social, and environmental aspects of sustainable development. It outlines 17 sustainable development goals (SDGs) and urban forests can contribute directly to meeting at least 9 (see section 7 for further details). SDG-11 aims to make cities "inclusive, safe, resilient and sustainable", and urban greening can impact these areas significantly. SDG-15 aims to protect life on land with a focus on biodiversity, afforestation, and climate resilience therefore cultivating a healthy and diverse urban forest is vital to cities like Belfast. This includes not just species and size diversity, but a greater evenness of green infrastructure across the city to provide environmental equality.

The EU Biodiversity Strategy for 2030 builds on key aspects of the UN Post-2020 Global Biodiversity Strategy and the Sustainable Development Goals. Though the UK is no longer part of the EU, policies like this continue to shape our national frameworks. Green infrastructure is identified as a key component, and it includes a call on European cities of at least 20,000 inhabitants to develop ambitious Urban Greening Plans by the end of 2021. The EU Strategy on Green Infrastructure adopted in 2013 is closely linked to the Biodiversity Strategy, calling for healthy green infrastructure to be developed, preserved and enhanced.

It has also been argued that more diverse forests and woodlands are more attractive, particularly when regarded in cities, thereby being of more value to the people. The UK's 25-Year Environmental Plan identifies the need to recover nature and enhance the beauty of landscapes. The Environmental Land Management Scheme has a chapter dedicated to the urban forest and identifies biodiversity as one of six vital 'public goods'.The Tree Health Resilience Strategy (2018) aims to protect trees from pests and disease. It emphasises working closely with industry and science to prioritise biosecurity. The goals include: a continued extent of trees; enhanced habitat connectivity, increased genetic and structural diversity, and the encouragement of healthy tree condition.

The Belfast agenda (2017) states "By 2035 Belfast will be a city that is vibrant, attractive, connected and environmentally sustainable". This statement alongside the Belfast Net Zero Carbon Roadmap (2020) and the Belfast Resilience Strategy (2020) which aims to "To transition to an inclusive, net zero-emissions, climate-resilient economy in a generation" show that there is a commitment to deliver the vision of a greener, more sustainable city by promoting a high quality environment which maximises the opportunities to improve energy efficiency, biodiversity and resilience. The 2021-2022 improvement plan shows this commitment being put into action: there is a commitment in response to Covid-19 "to support our city to recover by helping to restore the social and cultural vibrancy of our city spaces and places in a safe and sustainable way."

3.1 Ground Cover

Ground cover in Belfast (as measured using i-Tree Eco) consisted of approximately 56% permeable ‘green space’, such as grass and soil. Apart from a very small percentage (1.2%) of water, the remaining ground cover is made up of non-permeable surfaces such as brick, asphalt and concrete. These ‘hard’ surfaces absorb heat and contribute to a general warming of the urban environment.

The top three ground covers in the urban stratum are Tar 24%, Building 21% and Grass 20%. The top three ground covers in the rural stratum are Grass 64%, Herbaceous 13% and Mulch 7%.

Tree cover and shrub cover in the urban stratum stand at 15% and 9% respectively. Tree and shrub cover in the rural stratum stand at 15% and 8% respectively.

Plantable space is defined for i-Tree Eco as ‘*The amount of the plot area that is plantable for trees (i.e., plantable soil that is not under tree canopy or other overhead restrictions and where tree planting/establishment would not be prohibited due to land use, such as footpath, baseball field, etc.). Planting underneath utility wires is permitted*’[2].

Plantable space in the urban stratum stands at 24%.
Plantable space in the rural stratum stands at 65%.

Figure 2 (overleaf) shows distribution of ground cover in Belfast.

[2] i-Tree Tools, 2021

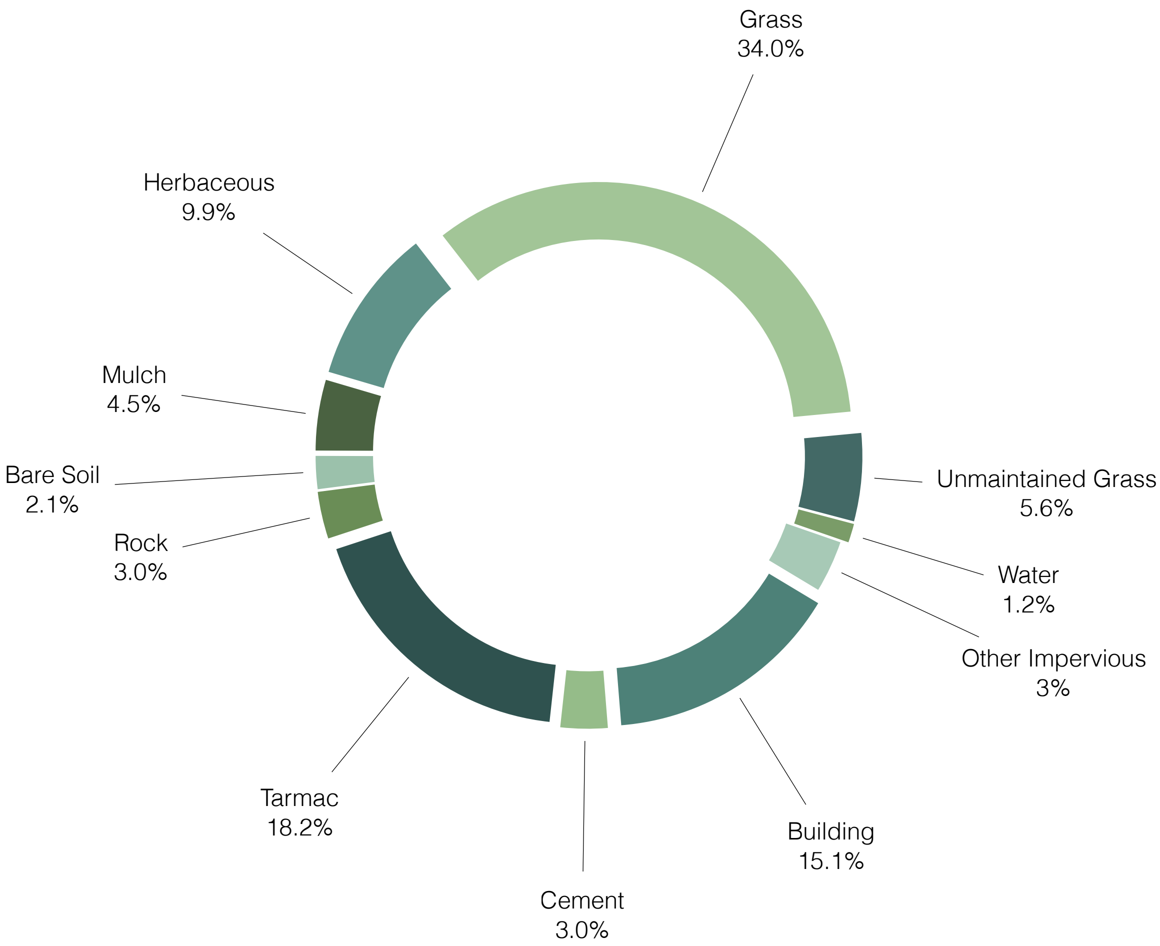

Figure 2: Percentage Ground Cover across Belfast estimated by Eco

3.2 Land Use

The surveyed plots indicate that in the urban stratum of Belfast over 37% of land is residential whereas in the rural stratum of Belfast only 6% of land is residential. This is balanced by the agricultural make up of land in the rural stratum which is estimated at 57%. Park/Parkland accounts for 18% of land cover across Belfast but is far more prevalent in the rural stratum of Belfast. Additionally there are similar proportions of Institutional 10%, Commercial & Industrial 9% and Transportation 7% land uses across the Belfast but these are mostly found in the urban stratum.

The top three land uses in the urban stratum are Residential 38%, Commercial/Industrial 17% and Transportation 11%.

The top three land uses in the rural stratum are Agriculture 57%, Park/Parkland 27% and Residential 6%.

Figure 3 (overleaf) shows the distribution of land use across Belfast.

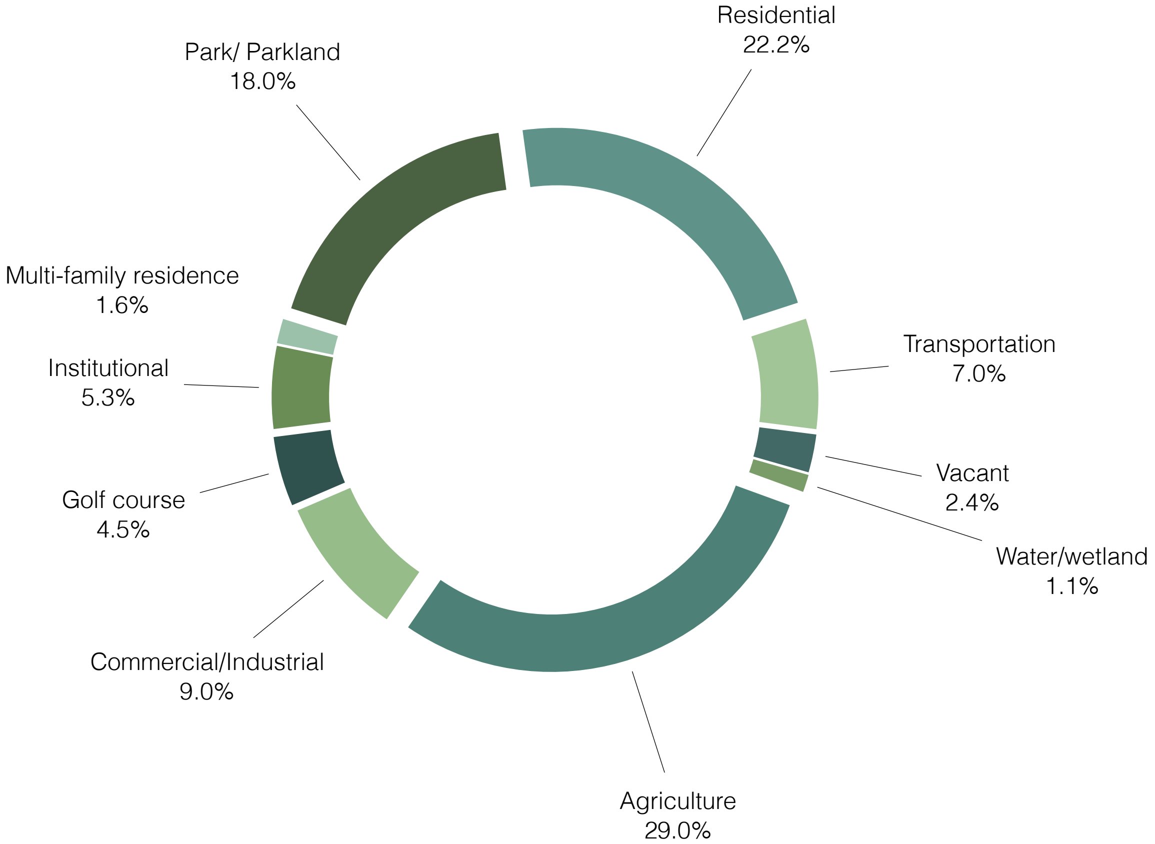

Figure 3: Percentage Land Use across Belfast estimated by Eco

3.3 Tree Species and Diversity

This Eco Sample survey identified 83 species in total, with 77 species identified in the ‘urban’ stratum and 35 in the rural stratum. The associated overall diversity index score is 3.6 according to the Shannon Weiner Index (3.7 in the ‘urban’ stratum and 2.8 in the ‘rural' stratum). This is a single number that takes account of two key concepts in diversity:

- Richness - the number of species
- Evenness - how equally they are represented

The higher the number, the greater the diversity. Figure 4 (below) shows the top ten percentage population of tree species across Belfast alongside all remaining species.

The most common species is *Fraxinus excelsior* (ash), representing 11% of the tree population. The second and third most common species are *Acer pseudoplatanus* (sycamore) representing 9% and *Fagus sylvatica* (beech) representing 5% of Belfast’s urban forest.

The urban stratum, made up of 77 species, the three most common species are *Fraxinus excelsior* (ash) 10%, *Prunus avium* (Wild cherry) 7% and *Acer psuedoplatanus* (sycamore) 6%. They collectively make up 23% of the urban stratum’s trees.

The rural stratum, made up of 35 species, the three most common species are *Acer pseudoplatanus* (sycamore) 16%, *Fraxinus excelsior* (ash) 14% and *Fagus sylvatica* (beech) 10%. They collectively make up 30% of the rural stratum’s 274,046 trees.

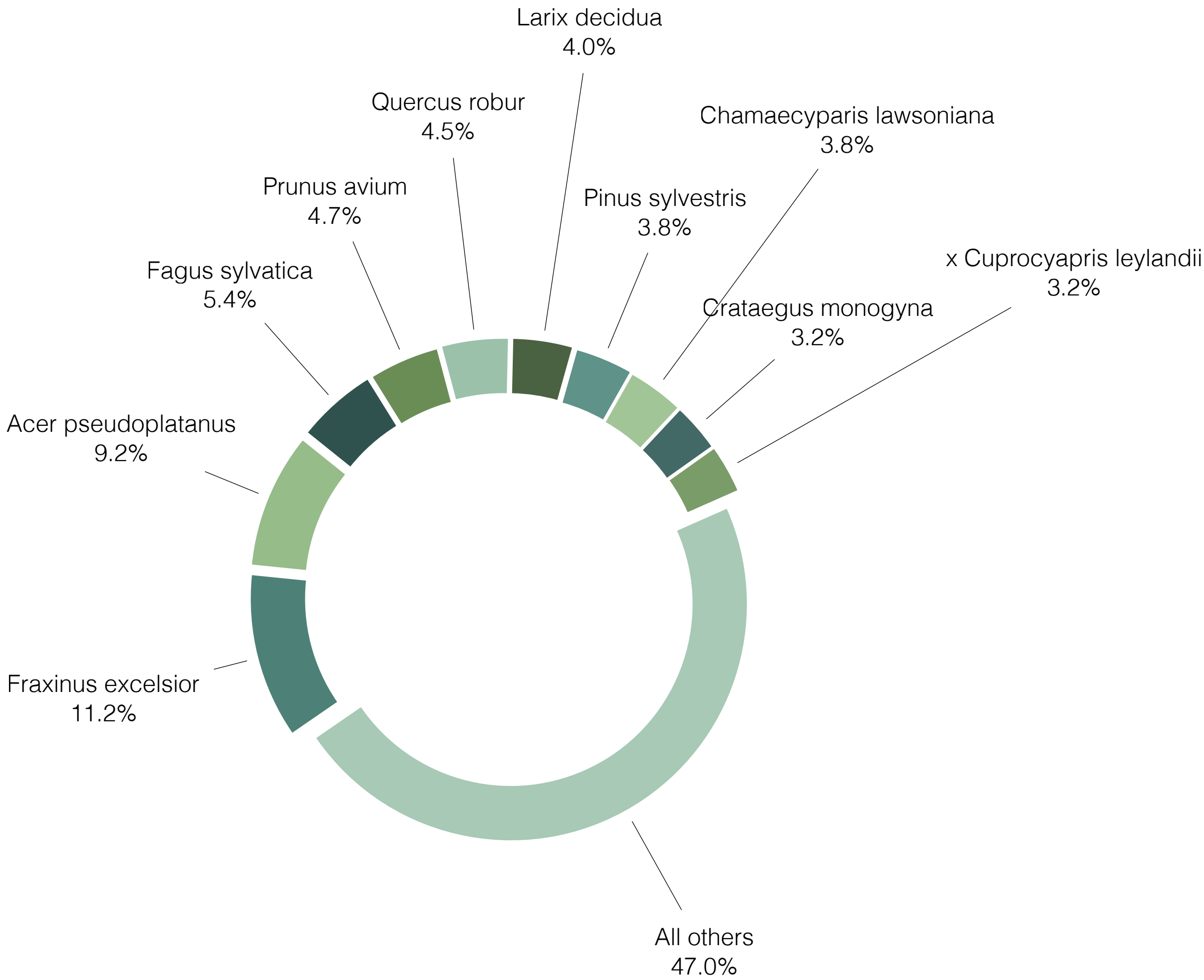

Figure 4: Percentage Population of Tree Species across Belfast

If dominance is just in terms of leaf area then this is fine, but if using the percent of leaf area + percent of population, i-Tree now refer to that as importance value

Santamour's 10-20-30[3] rule may be considered a useful tool in planning for maintaining diversity of species; the 10-20-30 rule is applied by some urban foresters as a rough guide to maintain a diverse population. This 'rule' suggests that no single species should represent more than 10% of any population, no single genus should represent more than 20% of a population and no single family should represent more than 30% of a population. This practice has been discussed by other authors such as Kendal[4] and Sjöman,[5] who have further examined the evidence and practicality.
In future it may also be useful to consider further diversifying the population towards meeting Barker's 1975 benchmark of 5% per species.[6]

In Belfast, no single genus represents more than 20% of the population, however the most common species, *Fraxinus excelsior* (ash) represents over 10% of the population. Though species diversity is high, a more even species distribution would help to make the urban forest more balanced and resilient. Appendix II contains a full list of species.

Diversity is an important aspect of the tree population to take into account. At a broader level, diversity occurs between genera and families, and this is an essential building block for a diverse urban forest. However, maintaining a high level of inter- and intra- species diversity is also key to urban forest sustainability. With more diverse tree populations, the likelihood that they will be vulnerable to a particular threat is lower and so a smaller proportion would be detrimentally affected. Species which originate from more distant regions to each other may be more genetically dissimilar and their presence may therefore increase resilience to environmental perturbations.

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[3] Santamour, 1999

[4] Kendal, 2014

[5] Sjöman *et al*, 2012

[6] Barker, 1975

The tree population within Belfast's urban forest represents a rich community of trees, with 83 species identified. Tree species represented in Belfast's urban forest inventory are primarily from three continents . Most of the species are native to Europe and Asia (see Figure 5 below). However, further work would be required to assess the condition, size and populations of these trees and to provide recommendations on the best species to choose for any future plantings.

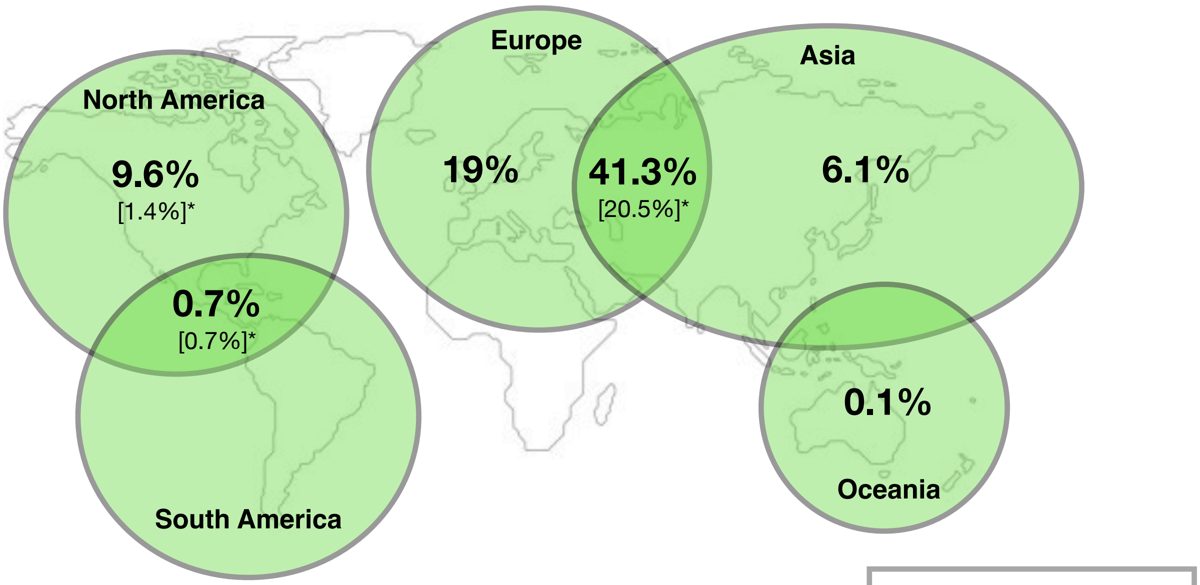

Figure 5: Origin of Tree Species: Share of trees native to different geographical regions. Overlaps indicate origins within both continents

*In these cases the proportion in brackets may include additional regions.
**Whilst there are still a few species whose origin remains unknown, most of these are hybrid *species* with a likely parentage from two zones rendering the concept of regional origin mute.

3.4 Leaf Area and Dominance

Leaf area is an important metric because the total surface area of a tree canopy is directly related to the amount of benefit provided. Generally the larger the canopy and its surface area, the greater the amount of air pollution or rainfall which can be held in the canopy of the tree.

Within Belfast's urban forest, total leaf area is estimated at 11,890 ha. If all the leaves within these tree canopies were spread out, they would cover an area over two and half times the size of the Lagan Valley Regional Park in south Belfast (4,500 ha)!

The most dominant[7] species in terms of leaf area is *Acer pseudoplatanus* (sycamore) accounting for 17% of the total leaf area. Second and third are *Fagus sylvatica* (beech) (15%) and *Fraxinus excelsior* (ash) (9%). Figure 6 (below) shows the top ten dominant trees' contributions to total leaf area. In total these ten genera, representing 45% of the tree population, contribute over 60% of the total leaf area.

In the urban stratum the three most dominant tree species in terms of leaf area are *Acer psuedoplatanus* 15%, *Fraxinus excelsior* 10% and *Fagus sylvatica* 9%. They make up 34% of the urban stratum's total leaf area.

In the rural stratum the three most dominant tree species in terms of leaf area are *Fagus sylvatica* 27%, *Acer psuedoplatanus* 21% and *Fraxinus excelsior* 7%. They make up 55% of the rural stratum's total leaf area.

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[7] In the UK we use the term 'Dominance' which is listed as 'Importance Value' within i-Tree.

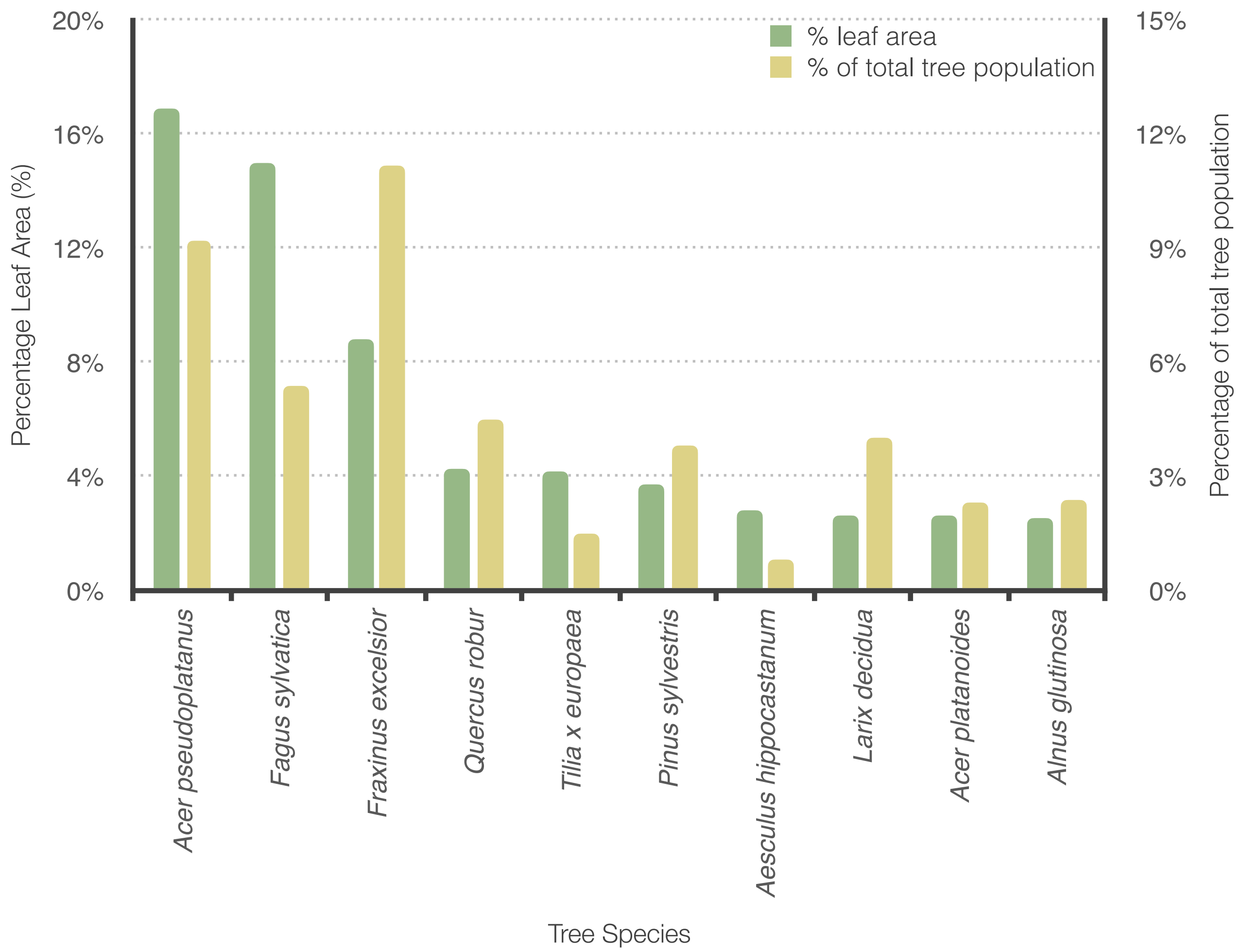

Figure 6: Percentage Leaf Area and Population of the Ten Tree Species With the Highest Leaf Area

Leaf area varies greatly between tree genera and species, depending on the size, shape and structure of both the individual leaves and the tree as a whole. Both sycamore and beech trees are good in this regard, and this is reflected in sycamore providing 17% of the total leaf area and beech providing 15% of the total leaf area in Belfast, despite only accounting for 9.2% and 5.4% of the total tree population respectively.

3.5 Size Distribution

Size class distribution is also an important aspect to consider in managing a sustainable and diverse tree population, as this helps ensure that there are enough young trees to replace those older specimens that are eventually lost through old age or disease. It is also relevant in terms of benefit delivery, as generally larger trees deliver greater benefits.

In Belfast's urban forest, trees were sized by diameter at breast height (DBH). Figure 7 (below) shows the percentage of the tree population for the ten most common tree species by DBH class. The chart represents a typical size class contribution for an urban area, displaying a negative correlation (with percentage composition declining as size increases). There is, however, some variation between species. If new plantings are made up of smaller stature species there will be a lack of larger trees in the future. To maintain or increase canopy cover and tree benefits at or above current levels then more trees capable of attaining larger statures will need to be planted and maintained.

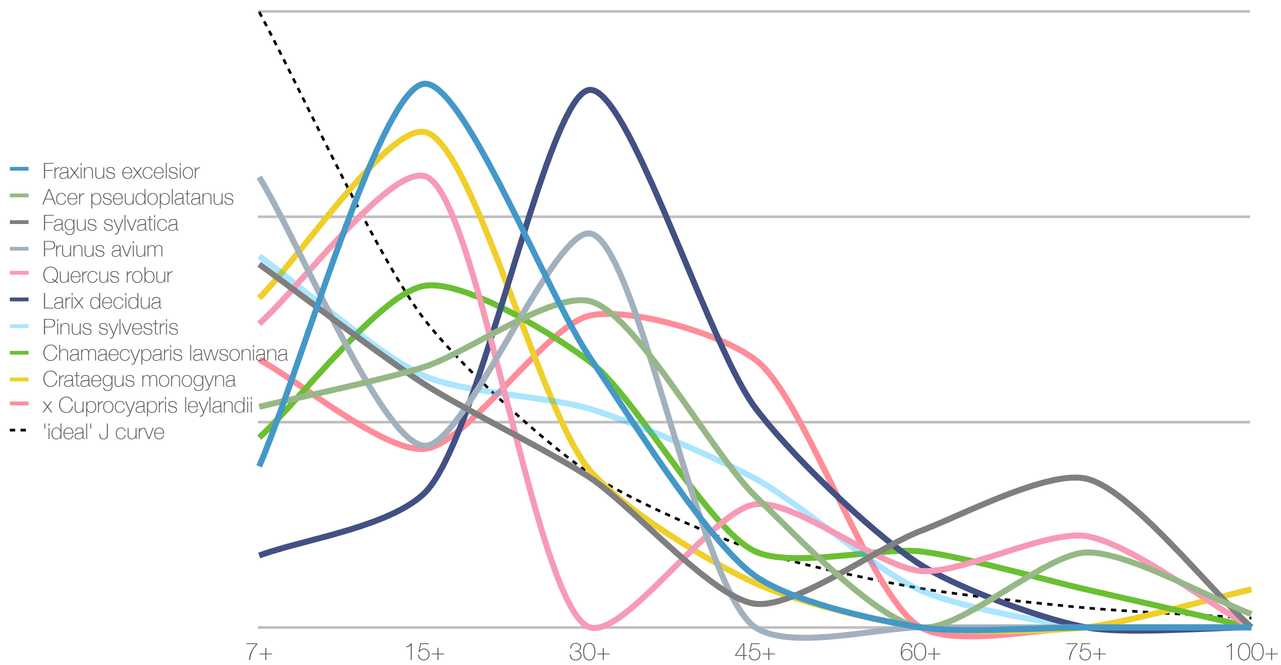

Figure 7: Spread of size classes amongst the top ten species, showing comparison to 'ideal' J-curve
'ideal' J-curve values reduce by half for each increase in DBH class

3.6 Recommendations for Structure and Composition

Despite Belfast already having 83 different species, there is room to improve the diversity and dominance and focus on larger stature, longer lived species. Though species diversity is high, more could be done to improve the species distribution to avoid reliance on a single species. The most common species is *Fraxinus excelsior* (ash) which accounts for 11% of the population. The top 10 most common species account for 53% of the total tree population.

The tree size distribution across the city was fairly typical of most urban landscapes, indicating that 63% of the top 10 most common trees have a DBH of 7-30cm, and 24% are between 30-60. Trees with a DBH greater than 90cm were the least common, representing less than 1% of the total tree population. Larger trees typically provide more ecosystem benefits to the community, and thus the more mature trees must be protected and managed to ensure they thrive and grow to their full potential.

In terms of species selection in relation to pest and disease, new planting should focus on further diversifying species which are currently at risk, and those with the potential to be impacted.

This study indicates that the tree density across Belfast is 61 trees/ha, and the tree canopy cover is approximately 14.5%, with a further 8.6% of large and small shrub cover.

Fraxinus makes up the largest proportion of trees in Belfast, with all *Fraxinus* species accounting for approximately 91,490 trees (11.3% total population). *Fraxinus excelsior* (ash) accounts for 9% of the total leaf area and is the third most dominant species in that regard. ash dieback poses a serious threat to these trees and is predicted to cause '*significant damage to the UK's ash population*'.[8]

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[8] Forest Research (2021)

The pressures associated with city living can increase trees susceptibility to pests and disease, most notably in those along streets and highways. These trees will require constant management to ensure they remain healthy, and to protect the diversity of the urban forest.

Given these findings, it is recommended that:

1. A wide variety of tree species are planted (with due consideration to local site factors) to increase diversity and reduce any over-reliance on dominant species identified as part of this study. This will lead to a more resilient population to our changing climate, and the impacts of pest or disease outbreaks.
2. Protection for existing mature and maturing trees is of great focus, together with increasing the planting of large-stature trees, (where appropriate) to increase canopy cover and the provision of benefits. Targeted planting in areas with low existing canopy cover can help to achieve greater evenness and increase environmental equality throughout the city.
3. Belfast should aspire to achieve 25% canopy cover by 2050. Part of this goal is achievable through protection and enhancement of existing trees (see 2 above).
4. In order to implement and monitor these recommendations, and those that follow in further sections, it is also recommended that:

    i. Belfast carefully plan future tree planting locations and species selection to achieve the recommendations listed above.

    ii. Belfast continues to communicate and promote the benefits of their urban forest with the community. Online resources such as WebMaps can be a great way to illustrate this information and show distributions across the city.

    iii. Belfast should produce a strategic Urban Forest Master Plan (with a vision for 2100). This plan should set out how these and other recommendations can be measured, targeted to areas of greatest impact and need, and implemented. In addition the plan should set out criteria for a repeat assessment in 5-7 years to monitor progress.

5. Further investigation should highlight barriers to the planting and establishment of tree in the lowest performing wards.
6. Work to further the engagement of local people through a Tree Warden scheme, and encourage the monitoring and maintenance of newly planted trees by local volunteers to ensure the survival of young trees.

Policy Context

Belfast's trees and green spaces are a critical resource securing a sustainable future for this vibrant city. The ecosystem services provided by trees are at the front line in the fight against climate change: cooling the air, filtering pollution, reducing stormwater run-off and storing carbon.

Urban trees are crucial to making city living sustainable, and can contribute to meeting global and national targets such as limiting the rise of global temperatures to below 2 degrees Celsius (The Paris Agreement), reaching carbon net neutrality by 2050 (UK Climate Change Act), and cutting greenhouse gas emissions by 68% by 2030 (The UK's Nationally Determined Contribution).

By sequestering and storing carbon, filtering air pollution and reducing surface water run-off, the urban forest contributes significantly to the achievement of the targets within the Sustainable Development Goals, the Kyoto Protocol, the New Urban Agenda, the National Planning Policy Framework, the 25-Year Environmental Plan, the Environmental Land Management Scheme, and many others. These policies and frameworks cover a vast range of issues, namely limiting the effects of climate change by sequestering carbon and reducing temperatures, ensuring the sustainable and efficient management of water resources, protecting people and property from both fluvial and coastal flooding, promoting equality in housing, opportunity, environment and education (amongst others), driving for biodiversity net gain and many more issues besides.

At a local level, Belfast has several documents pertaining to the sustainability and the environment. These include Belfast's environmental policy statement, the Belfast Local Development Plan, the Belfast Green and Blue infrastructure plan, the Belfast Resilience Strategy, the Net-zero Carbon Roadmap for Belfast, the Belfast air quality action plan, the Belfast Agenda, Belfast's Open Strategy, the Tree Strategy and the Belfast One Million Trees campaign. These aim to incorporate the goals of the overarching international and national policies into development and management methods to be used across different sectors, both public and private, within the city. In some areas provide structured guidelines to ensure that future development in Belfast can maximise the benefits of trees and green infrastructure, and promote sustainable growth.

4. Ecosystem Service Provision

Trees provide a wide range of services, and urban trees in particular are under significant pressures to perform. Air pollution in cities causes health problems, excess storm water run-off can cause flooding, and increasing built environments along with human activity in urban areas can raise temperatures to as much as 9°C compared to surrounding rural landscapes in the UK, this phenomenon is known as the ‘Heat Island Effect’.[9] Trees are a significant advantage in the fight to reduce these issues and minimise the risks they present to people.

[9] Chartered Foresters, 2016

4.1 Air Pollution Removal

Poor air quality is a common problem in many urban areas, in particular along transport corridors. Air pollution caused by human activity has caused issues since the beginning of the industrial revolution. With increasing populations and industrialisation, large quantities of pollutants are produced and released into the urban environment. The problems caused by poor air quality are well documented, ranging from severe health problems in humans to damage to buildings.

Urban trees can help to improve air quality by reducing air temperature and directly removing pollutants.[10] Trees intercept and absorb airborne pollutants on to the leaf and bark surface.[11] By removing pollution from the atmosphere, trees can reduce the risks of respiratory disease and asthma, thereby contributing to reduced healthcare costs.[12]

Trees emit volatile organic compounds (VOCs) that can contribute to low-level ozone formation which is detrimental to human health. However, VOC's emissions are temperature dependent, and integrated studies have revealed that an increase in tree cover leads to a general reduction in ozone through a reduction in air temperature[13][14]. Eco accounts for both reduction of ozone and production of VOCs within its algorithms, Eco estimated that the surveyed trees in Belfast contribute to a net reduction in ozone concentrations as seen in figure 8 (below).

Across Belfast it is estimated that the trees of the urban forest remove over 211 tonnes of pollutants from the atmosphere each year, with an associated value of £7,460,000.

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[10] Tiwary et al., 2009

[11] Nowak et al., 2000

[12] Peachey et al., 2009. Lovasi et al., 2008

[13] Nowak, 2002

[14] Nowak et al., 2000

This includes nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and particulate matter 2.5 µm or smaller ($PM_{2.5}$). Figure 8 (below) shows a breakdown of the pollution removal and the associated values provided by Belfast's urban forest.

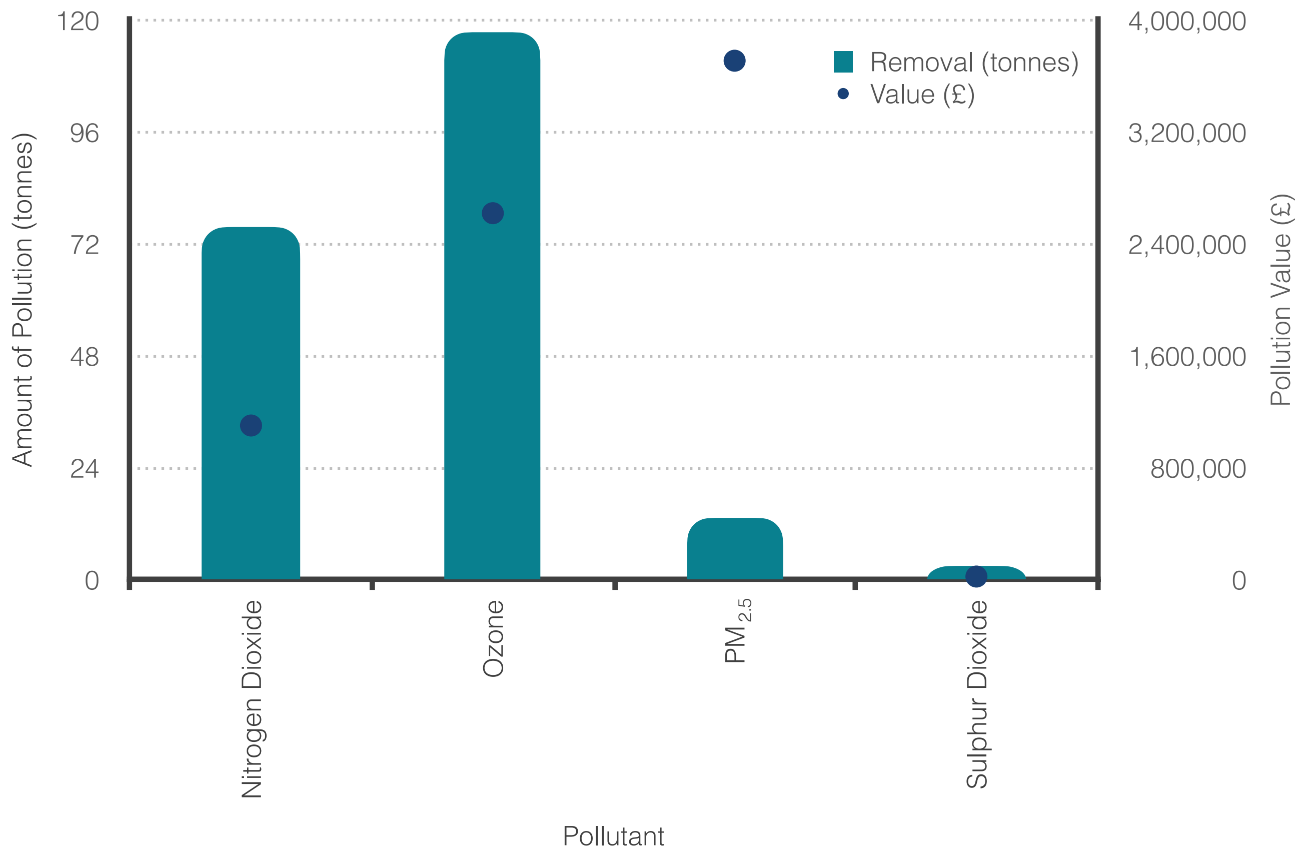

Figure 8: Value of the Pollutants Removed and Quantity Per-Annum

The valuation method uses, where available, UK social damage costs (UKSDC). Where there are no UK figures, the US externality cost (USEC) is used as a substitution. These US costs were used for ozone only.

Based on the percentage of the total tree population that is located in the urban stratum (66%), the estimated pollution removal by the trees in the urban stratum is 139 tonnes per year, with a value of £4.9 million. It should be noted that this does not take into account the species composition in the urban stratum. A limitation of i-Tree Eco is that it cannot provide pollution removal estimates by stratum.

Based on the percentage of the total tree population that is located in the rural stratum (34%), the estimated pollution removal by the trees in the rural stratum is 72 tonnes per year, with a value of £2.9 million. It should be noted that this does not take into account the species composition in the urban stratum. A limitation of i-Tree Eco is that it cannot provide pollution removal estimates by stratum.

Greater tree cover, pollution concentrations and leaf area are the main factors influencing pollution filtration and therefore increasing areas of tree planting have been shown to make further improvements to air quality. Furthermore, because filtering capacity is closely linked to leaf area, it is generally the trees with larger canopy potential that provide the most benefits.

Figure 9 (below) shows the breakdown for the top ten pollution removing species across Belfast's urban forest.

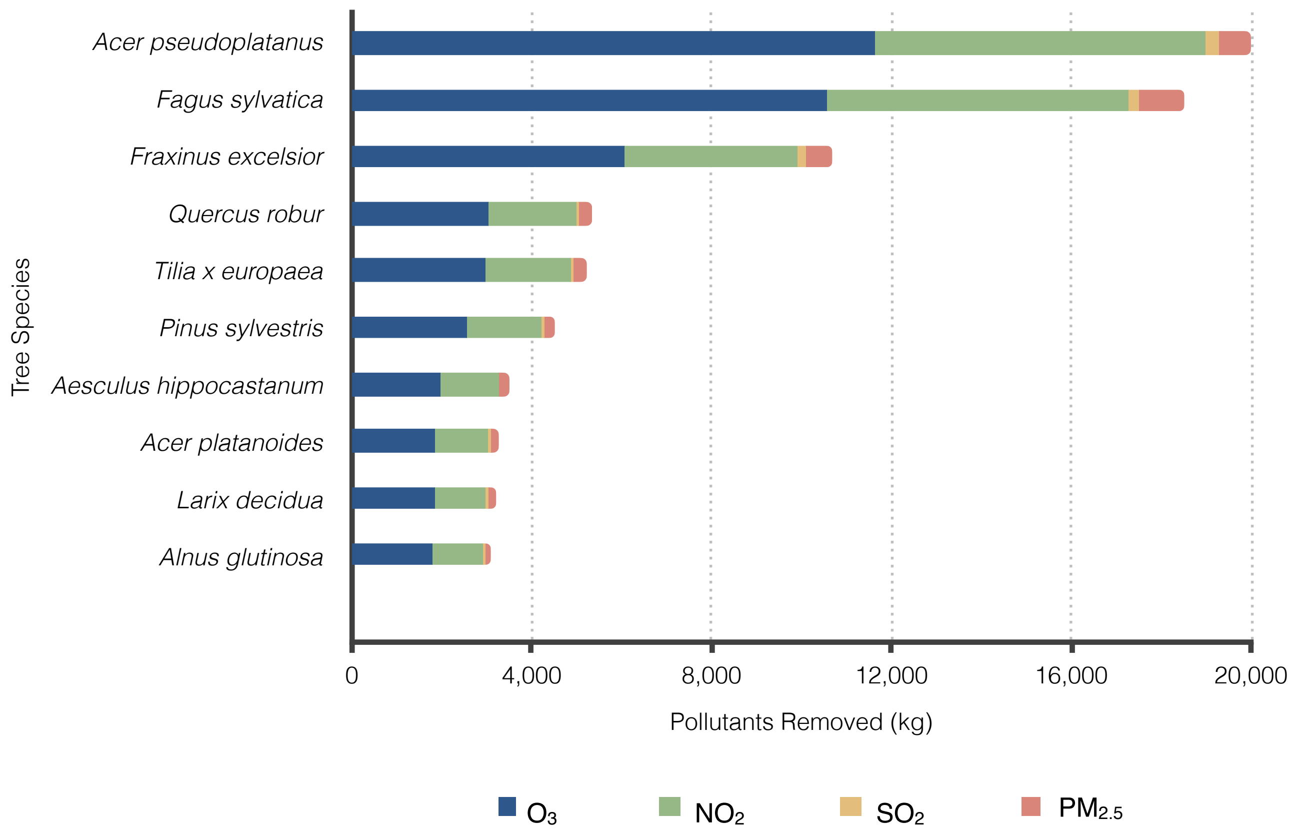

Figure 9: Pollution Removal by Tree Species

As different species can capture different sizes of particulate matter,[15] it is recommended that a broad range of species should be considered for planting in any air quality strategy. Typically the canopy of deciduous trees have a greater leaf area, however they do lose their leaves during the autumn and winter and therefore cannot provide these benefits year round like their evergreen counterparts.

The top three species for pollution removal across Belfast's urban forest are *Acer pseudoplatanus, Fagus sylvatica* and *Fraxinus excelsior.*

[15] Freer-Smith et al. 2005

4.2 Carbon Sequestration

The trees in Belfast's urban forest trees sequester an estimated 8,890 tonnes of carbon per year, with a value of £8,090,000.

Table 5 (below) shows the top ten species in terms of annual carbon sequestration across Belfast's urban forest, and the value of the benefit derived from the sequestration of this atmospheric carbon.

Species	Carbon Sequestration (tonnes/yr)	CO_2 Equivalent (tonnes/yr)	Carbon Sequestration (£/yr)
Acer pseudoplatanus	1,160	4,230	£1,050,000
Fraxinus excelsior	869	3,190	£790,000
x Cuprocyapris leylandii	771	2,830	£701,000
Quercus robur	538	1,970	£489,000
Fagus sylvatica	450	1,650	£409,300
Tilia x europaea	399	1,460	£363,000
Larix decidua	314	1,150	£285,000
Acer platanoides	304	1,120	£277,000
Prunus avium	298	1,090	£271,000
Pinus sylvestris	290	1,060	£264,000
All Other Species	**3,510**	**12,900**	**£3,190,000**
	8,890	**32,610**	**£8,090,000**

Table 5: Top Ten Carbon Sequestration by Species from across Belfast

The trees in the urban stratum of Belfast's urban forest sequester an estimated 6,359 tonnes of carbon annually which is 72% of Belfast's urban forests total annual carbon sequestration at a value of approximately £5.8 million.

The trees in the rural stratum of Belfast's urban forest sequester an estimated 2,534 tonnes of carbon annually which is 28% of Belfast's urban forests total annual carbon sequestration at a value of approximately £2.3 million.

4.3 Carbon Storage

The main driving force behind climate change is the concentration of carbon dioxide (CO_2) in the atmosphere. Trees can help mitigate climate change by storing and sequestering atmospheric carbon as part of the carbon cycle. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots can store up to several tonnes of carbon for decades or even centuries.[16] As trees die and decompose they release the stored carbon. The carbon storage of trees and woodland is an indication of the amount of carbon that could be released if all the trees died. Maintaining a healthy tree population will ensure that more carbon is stored than released.

Overall, the trees in Belfast's urban forest store an estimated 318,626 tonnes of carbon with a value of approximately £290 million. Figure 10 (below) illustrates the top ten carbon-storing tree species across Belfast’s urban forest.

The trees in the urban stratum of Belfast’s urban forest store an estimated 222,406 tonnes of carbon which is 70% of Belfast’s urban forests total carbon storage at a value of approximately £202 million.

The trees in the rural stratum of Belfast’s urban forest store an estimated 96,220 tonnes of carbon which is 30% of Belfast’s urban forests total carbon storage at a value of approximately £87.5 million.

[16] Kuhns 2008, Mcpherson 2007

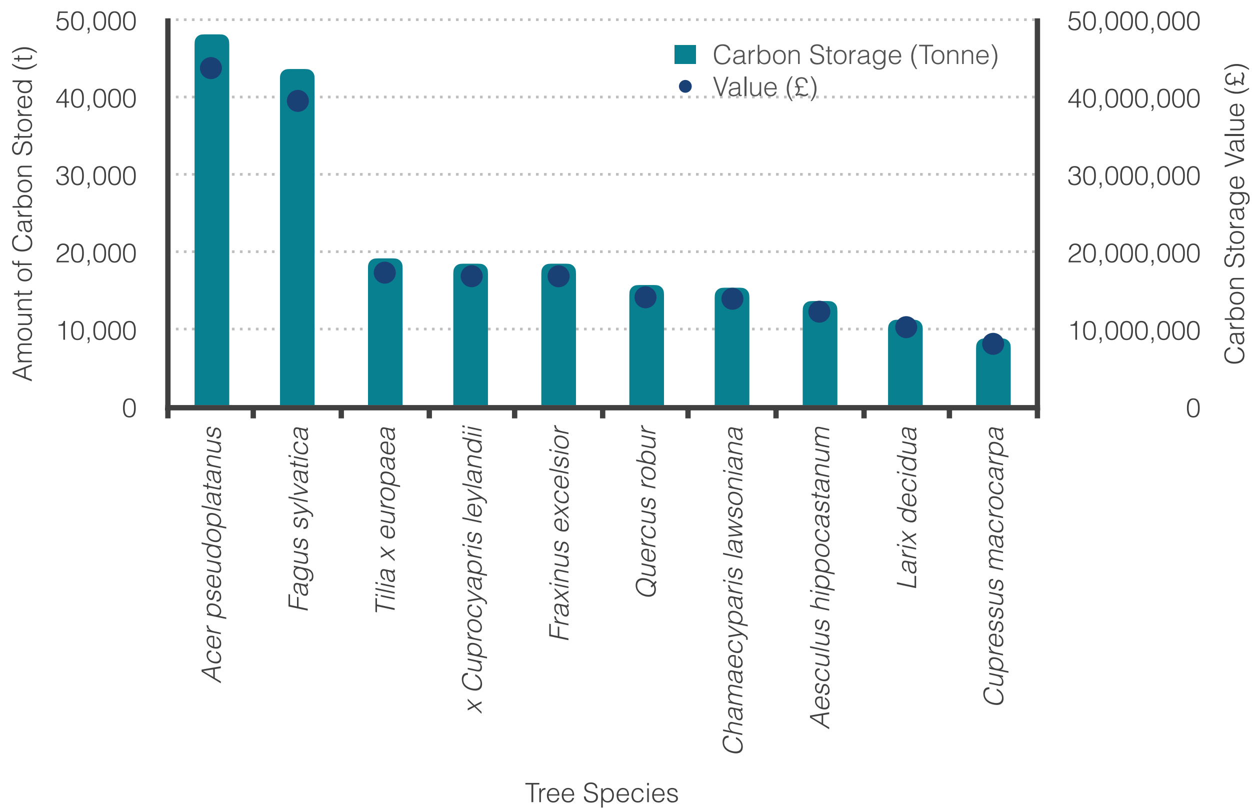

Figure 10: Carbon Storage for Top Ten Tree Species across Belfast

Acer pseudoplatanus is the species that stores the most carbon across Belfast, around 48,000 tonnes of carbon worth over £43 million. This is likely due to the morphology and size of trees in the population. This is followed by *Fagus sylvatica* which stores 43,500 tonnes of carbon worth over £39 million. The top ten species shown above in figure 10 species store 67% of the carbon within Belfast's urban forest at a combined value of just under £194 million!

The Role of Trees and Other Natural Systems for Carbon Storage and Sequestration

Nature-based solutions is a broad concept which encompasses the protection, restoration, and management of natural systems to help solve societal problems such as climate change. Transforming degraded habitats into healthy, functioning ones offers significant potential for sequestering carbon dioxide from the atmosphere. Protecting existing habitats ensures that the carbon stored within them, which may have taken thousands of years to accumulate, isn't lost to the atmosphere.[17]

Urban woodlands, hedges, trees outside woodlands, grass in parks, and green roofs can all contribute to climate change mitigation by storing and sequestering carbon from the atmosphere.

Carbon is stored in and sequestered by both soil and vegetation. Globally, soils store nearly 80% of all terrestrial organic carbon[18], and in many semi-natural habitats the soil is the most important component.

Native broadleaved woodlands are the most effective habitat for sequestering carbon from the atmosphere (including the soil and the vegetation), and old woodlands are important for carbon storage.

In UK urban areas there is rarely space for creation of swathes of woodland. Trees outside woodlands will also sequester and store carbon, as well as provide numerous benefits that contribute to climate change adaptation, including providing shade, reducing run-off, and absorbing air pollution.

Open habitats such as grassland (including the soil and the vegetation therein) store and sequester less carbon than woodlands but store more than modern agricultural land. Open park spaces with maintained grass can play their part in carbon storage and sequestration, where low-carbon management methods are prioritised.

For more information, see Appendix IV.

[17] Gregg et al., 2021

[18] Ontl and Schulte, 2012

4.4 Hydrology - Avoided Surface Runoff

Surface runoff can be a cause for concern in many areas as it can contribute to flooding and is a source of pollution in streams, wetlands, waterways, lakes and oceans. During precipitation events, a proportion is intercepted by vegetation (trees and shrubs) while the remainder reaches the ground. Precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff.[19]

In urban areas, the large extent of impervious surfaces increases the amount of runoff. However, trees are very effective at reducing surface runoff.[20] Tree canopies intercept precipitation, while root systems promote infiltration and storage of water in the soil. Annual avoided surface runoff in Eco is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation.

The trees within Belfast's urban forest reduce runoff by an estimated 317,000 m^3 each year with an associated value of £593,000. This volume is equivalent to approximately 127 Olympic swimming pools of surface runoff being averted every single year. Figure 11 (below) shows the volumes and values for the ten most important species for reducing runoff across Belfast's urban forest.

[19] Hirabayashi 2012

[20] Trees in Hard Landscapes (TDAG) 2014

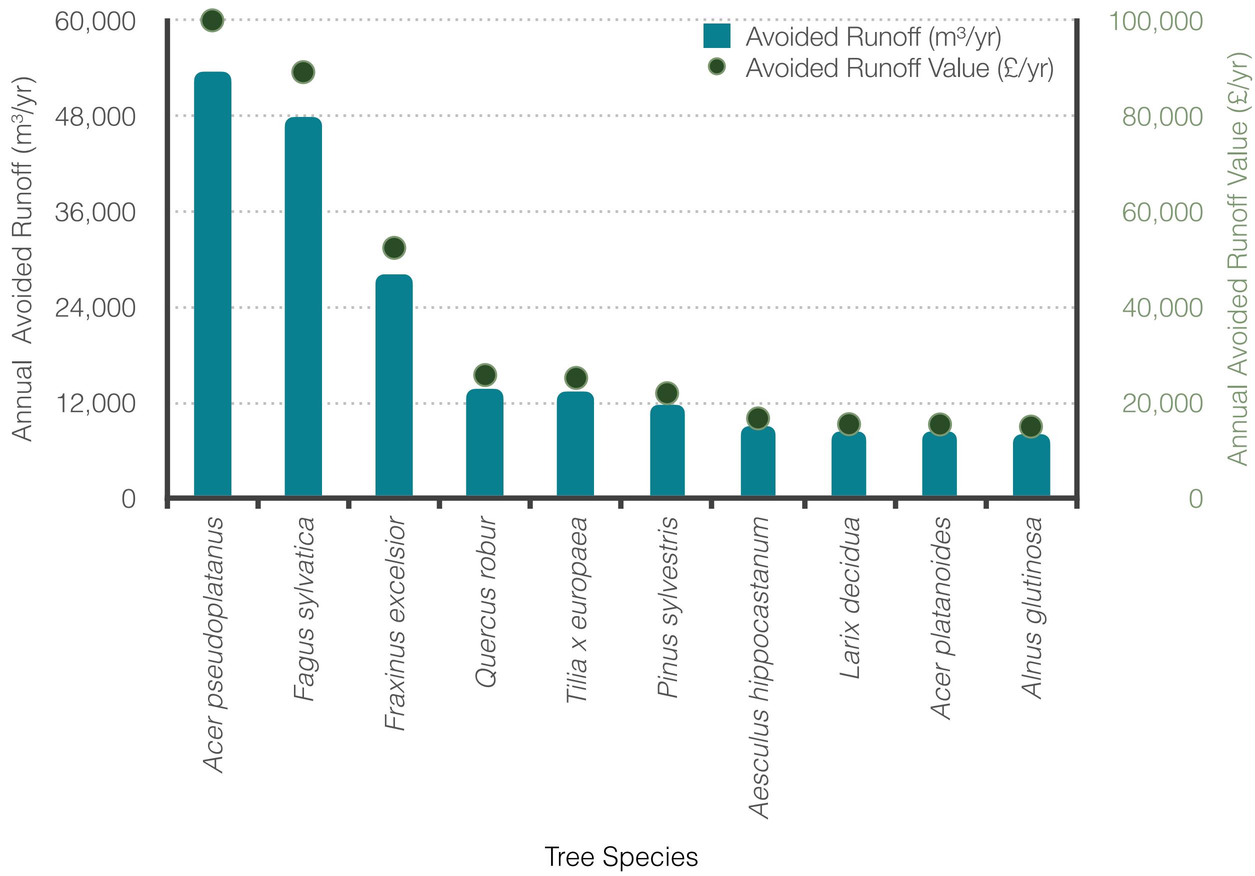

Figure 11: Annual Avoided Runoff and Associated Value by Top Ten Species

The trees in the urban stratum of Belfast's urban forest reduce runoff by 205,000 m^3 which is 65% of the total surface runoff reduction at a value of approximately £383,000.

The trees in the rural stratum of Belfast's urban forest reduce runoff by 112,247 m^3 which is 35% of the total surface runoff reduction at a value of approximately £210,000.

4.5 Additional Benefits

Trees in the urban forest have a unique role within the City of Belfast. They affect the immediate surroundings of the people who live and work in the area, providing benefits such as insulation, shade and habitats for wildlife. It is vital that these amenities are considered in planning and development to provide maximum benefits and ensure green infrastructure is incorporated where it is needed most.

Policy Context

Green infrastructure is a vital part of any cityscape. It provides ecosystem services, adds amenity value to the area, and can even increase property value. As such, urban forest and green infrastructure have become key policy areas pertaining to design and development. The UN's 2030 Agenda identifies the benefits of the urban forest in SDG-8, and pushes for this to be considered in policy at a national and local level.

The National Planning Policy Framework (NPPF) sets out the Governments planning policies for England and provides a framework within which plans for local housing and other development can be produced. Of the 16 sections in the revised NPPF, trees are able to contribute to meeting the objectives of 11 of them. Section 12 of the NPPF "Achieving well-designed places" refers in many places to the benefit of careful consideration of the use of trees in development design. Section 14 refers to the role of planning in responding to the changing climate. Commonly referenced is the ability of trees to "Conserve and enhance the natural environment" (Section 15).

The 25-Year Environmental Plan is based on the UN's 2030 Agenda, and has outlined six key policy areas, five of which relate to urban forest. Incorporating green infrastructure can help achieve these by connecting people with the environment to improve health and wellbeing, recovering nature and enhancing the beauty of landscapes, increasing resource efficiency, and reducing pollution and waste, and using and managing land sustainably by embedding an 'environmental net gain' principle for development, including housing and infrastructure.

At a local level, Belfast has several documents which provide guidance for developers on sustainable design and green infrastructure.

- The Belfast Agenda
- The Belfast resilience assessment
- Draft Local Development Plan
- Future proofed city - Belfast Resilience Strategy Assessment
- Future proofed city - Belfast Ambitions Document: A Climate Plan for Belfast
- Cultural Strategy
- Open Spaces Strategy
- Green and Blue Infrastructure Plan

The Tree & Design Action Group (TDAG) provide several guides and resources aimed at urban planners to aid the incorporation of green infrastructure within cities. The First Steps in Valuing Trees and Green Infrastructure guide compiles information and advice about the use of economic valuation approaches for trees and green infrastructure, which tool or method to choose and how to get started. It outlines four general scenarios where valuing trees and green infrastructure deliver proven results. These include: achieving greater retention of existing green assets, securing more commensurate compensation when green assets are compromised or lost, enhancing design outcomes and how those outcomes are communicated, and, enabling evidence-based management.[21]

TDAG's best practice guide 'No Trees, No Future' emphasises the importance of considering trees in the early stages of design and incorporating allowances for fully mature trees from the outset. Although national and local policy tends to encourage planting trees in urban areas, the way that new development is delivered often makes it impossible to accommodate larger trees. This is a huge issue, however there are ways to overcome these challenges, for example in high density developments there may be less room for tree roots and canopies, however space can often be found along boundaries, adjacent to paths, or in areas of public open space.[22]

Whilst subsidence caused by trees is a risk perceived by many, it is actually far less common than often insinuated. One study in a London borough found that only 0.05% of its building stock was affected by tree-related insurance claims annually, and in areas where the subsoil is not shrinkable clay the risk is minor. These types of foundation movement are likely to increase — whether or not trees are present — as the effects of climate change increase.[23] Trees can actually affect buildings in a positive way, providing energy savings, summertime cooling and providing oxygen and air pollution removal which saves on air filtration.

[21] TDAG-First Steps in Valuing Trees and Green Infrastructure (2019)

[22],[23] TDAG-No Trees, No Future (2010)

Energy effects

Trees can provide energy saving benefits to nearby buildings through by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months. In doing so, the property typically requires less heating/cooling, and therefore uses less energy. In turn, this reduces the amount of carbon released by the traditional methods of energy production. Trees less than 3m tall or further than 18m away from buildings do not provide these benefits, and owing to the nature of the data collected it is difficult to quantify this for the whole of Belfast, however the average carbon avoidance provided by a single tree for the surveyed trees is 3.34kg/yr.

Oxygen provision

The trees across Belfast's provide an estimated 13.34 thousand metric tonnes of oxygen each year. The average human breathes about 9.5 tonnes of air in a year, but oxygen only makes up about 23% of that. Little over a third of the oxygen from each breath is extracted, therefore we use about 740kg of oxygen per year.[24] The trees in Belfast therefore provide breathable air to 46,480 people each year-thats 13.5% of the population of Belfast!

UV effects

[24] https://www.theconsciouschallenge.org/ecologicalfootprintbibleoverview/oxygen-global-overview

UV radiation is emitted by the sun and while beneficial to humans in small doses, can have negative health effects when people are overexposed. Trees protect people from UV rays by providing shade, blocking sunlight from directly reaching the ground. Shade provision can help keep buildings and roads cool in the summer and reduce the heat island effect associated with cities.[25]

Table 6 (below) shows the effect Belfast's trees have on UV factors. The effects in tree shade indicates the reduction in UV for a person entirely in the shade. The UV effects overall are for people in the vicinity of the tree but not always sheltered, for example walking down the street, sometimes in shade and sometimes exposed.

	Protection Factor	Reduction in UV Index	Percent reduction (%)
UV Effects in Tree Shade	2.1	1.6	49.3
UV Effects Overall	1.3	0.6	23.0

Table 6: UV Effects of Trees in Belfast

Protection Factor is a value meant to capture the UV radiation blocking factor of trees and is comparable to the SPF factor of suncream. The UV index scale was developed by the World Health Organization to more easily communicate daily levels of UV radiation and alert people to when protection from overexposure is needed most.

[25] TDAG-No Trees, No Future (2010)

4.6 Recommendations for Ecosystem Services

Belfast's trees provide a wide range of benefits. However, for these benefits to be maximised there has to be an identified need. The trees also need to be healthy and function efficiently. Selecting the right species and location will help to enable trees to perform to their maximum capacity. Preferably, the impact needs to quantifiable too. Therefore it is recommended that (continued from above):

7. A review is conducted of the 'potential plantable space' which could be mapped against local air quality and social indicators such as the index of multiple deprivation alongside tree cover in order to identify and prioritise spaces and places where the addition of trees could help meet local need in the lowest performing wards.

8. Areas identified of most need are targeted to investigate on a site-by-site basis for tree planting suitability. The results should also be challenged by experts with local knowledge and experience as there may be 'barriers' to tree planting in the identified areas which will need to be addressed.

9. Species are selected that are appropriate to the site to maximise tree benefit delivery and realise the full site potential. Engaging with local communities can have a large impact on the successfulness of planting initiatives, and tree wardens can be a huge asset in achieving this.

10. Prioritise planting of large-leaved long lived species over smaller, ornamental species to maximise the ecosystem services provided (where appropriate).

11. Incorporate trees and green infrastructure from the outset of urban design and planning processes. Consideration of urban forests at this stage can help to protect

these valuable resources and maintain balance between green spaces and grey infrastructure.

12. The development of any tree planting programs need to be sustainable and to be co-ordinated with other local stakeholders as part of a larger sustainable urban forest masterplan for Belfast. This should also include management strategies to help trees reach their full potential in the built environment.

5. Potential Pests and Diseases

Pests and diseases are a serious threat to urban forests. It is likely that climate change will result in the introduction of pests and diseases not yet present in the UK. Warmer temperatures are likely to affect the geographical range, development rate and seasonal timing of life-cycle events of insects, and will have an impact on their host plants and natural enemies.[26] The changing climate of the UK is predicted to increase growth or spore release of root pathogens, and to make trees more susceptible to infection.[27]

It is important to consider the impacts of existing and potential pests and diseases when planning and managing an urban forest. Ash sawfly (*Tomostethus nigritus*) is present in Belfast and has been known to cause extensive defoliation of ash trees, which are already threatened by damage from Chalara dieback. These and other pests and diseases have been considered in terms of the likelihood of their spread to Northern Ireland, the percentage of Belfast's tree population they could affect, and the estimated CAVAT value of those trees (for more information on estimated CAVAT values for Belfast's urban forest, please see Chapter 7).

Table 7 (below) shows the risk matrix used to assess the probability of a pathogen affecting trees from a single genus in Belfast's urban forest. Table 8 (below) shows the risk matrix for pathogens that affect trees in multiple genera. In both cases, the higher the percentage of the tree population and the more likely that the pathogen is already present in Northern Ireland, the greater the probability of that pathogen having an adverse impact in Belfast's urban forest. Many pests and diseases can infect a whole range of tree species but only the species recorded in the i-Tree survey were considered here.

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[26] Wainhouse and Inward, 2016

[27] Frederickson-Matika and Riddell, 2021

	% of tree population		
Prevalence	0–5%	6–10%	>10%
Not in UK			
Present in UK			
Present in Northern Ireland			

Table 7: Risk matrix used for the probability of a pest or disease becoming prevalent in Belfast's urban forest on a single genus (one or more species).

	% of tree population		
Prevalence	0–25%	26–50%	>50%
Not in UK			
Present in UK			
Present in Northern Ireland			

Table 8: Risk matrix used for the probability of a pest or disease becoming prevalent in Belfast's urban forest on multiple genera.

Table 9 (below) gives an overview of some of the established and emerging pests and diseases that could have a significant impact on Belfast's urban forest. Only species which are currently present in Belfast have been included. The risk of a pest or disease spreading to Northern Ireland is based on the Defra plant health portal, and DAERA's plant health risk register for Northern Ireland.

The most significant threats to Belfast's trees come from Chalara dieback of ash and ash sawfly, which are both present in Northern Ireland and threaten 11.3% of the urban forest with an estimate CAVAT value in excess of £240 million. The pest posing a threat to the greatest percentage of Belfast's trees is the Asian longhorn beetle. It attacks numerous broadleaf species and is a major pest in countries where it is established. Thanks to control measures, the risk of it spreading to Northern Ireland is low.

Pest/ Disease	Tree species affected	Prevalence in the UK	Prevalence in Northern Ireland	Risk of spreading to Northern Ireland	Urban forest population at risk (%)	CAVAT value of urban trees (£)
Acute oak decline	*Quercus robur, Q. petraea*	Central and South East England, Welsh borders	None	Medium risk	5.6%	£252 m
ash sawfly	*Fraxinus excelsior, F. angustifolia*	Isolated outbreaks in England, Wales, Scotland and Northern Ireland	Outbreaks confined to Belfast	Already present	11.3%	£242 m
Asian longhorn beetle	Many broadleaf species	None (previous outbreaks contained)	None	Low risk	62.3%	£2,612 m
Bronze birch borer	*Betula spp.*	None	None	Low risk	5.9%	£105 m
Chalara dieback of ash	*Fraxinus excelsior*	Throughout England, Wales, Scotland, and Northern Ireland	Throughout Northern Ireland	Already present	11.3%	£242 m
Emerald ash borer	*Fraxinus excelsior, Ulmus spp.*	None	None	Medium risk	12.6%	£284 m
Ips typographus	*Picea spp., Pinus spp., Abies spp.*	Present in South East England (contained)	None	Low risk	6.6%	£301 m
Oak processionary moth	*Quercus spp.*	Established in London and South East England	None	Medium risk	5.6%	£252 m
Oak wilt	Quercus *spp.*	None	None	Low risk	5.6%	£252 m

Pest/ Disease	Tree species affected	Prevalence in the UK	Prevalence in Northern Ireland	Risk of spreading to Northern Ireland	Urban forest population at risk (%)	CAVAT value of urban trees (£)
Phytophthora lateralis	*Chamaecyparis lawsoniana*	Isolated confirmed cases throughout UK. Most common in Scotland and Northern Ireland.	Throughout Northern Ireland	Already present	3.8%	£371 m
Phytophthora ramorum	*Larix spp., Castanea sativa, Fagus sylvatica, Quercus rubra, Q. cerris, Q. ilex, Aesculus hippocastanum*	Throughout England, Wales, Scotland, and Northern Ireland	Throughout Northern Ireland	Already present	36.0%	£1,552 m
Pine processionary moth	*Pinus spp.*	None	None	Low risk	6.3%	£289 m
Xylella fastidiosa subsp. multiplex*	*Quercus robur, Q. rubra, Ulmus glabra, Platanus occidentalis, Acer pseudoplatanus, Prunus cerasifera*	None (one previous interception in the UK)	None	Low risk	15.1%	£874 m

Table 9: Risk assessment of selected tree pests and diseases for Belfast's urban forest.

*This is one of four subspecies of *Xylella fastidiosa*. There is potential to affect a more extensive range of ornamental plant species when taking the other subspecies into consideration.

5.1 Chalara dieback of ash

Chalara dieback of ash, also known simply as ashDieback (*Hymenoscyphus fraxineus*) is a major problem currently faced in the UK. This vascular wilt fungus causes the dieback and can often lead to the death of ash trees. ashDieback is harmless in its native range in Asia, associating with native ash species including *Fraxinus mandshurica*. However, other Fraxinus species, particularly ash (*Fraxinus excelsior*), which is the greatest species in Belfast in regards to tree number, has shown to be highly susceptible to the pathogenicity of *H. fraxineus*. Whilst thought to have been introduced to Europe in 1992, it was first discovered in the UK at a nursery in Norfolk in 2012. It has had a major impact upon the ash population in several countries, and since being found in the UK, the rate of infection has increased at a steady rate and widely present in continental Europe and Ireland. The greatest public risk from ashdieback is likely to be found in areas such as highways and trackways. ash trees on these sites are subject to significant stress factors, such as high salt content in soils due to winter salting, which can increase disease susceptibility.

The risk to the trees in Belfast is very high, as ashDieback is already present in the area. *Fraxinus* accounts 11% of the population (over 10,000 individual trees) making it the genus with the most trees in Belfast, species include *F. excelsior*. *Fraxinus excelsior* is the fifth highest carbon storing species, the second highest carbon sequestering species, and the third best at intercepting stormwater and removing pollution from the atmosphere. They are a significant presence in Belfast and should be carefully managed to prevent a massive drop in canopy cover and ecosystem service provision over then next decade. The total replacement cost for these trees is over £67 million.

5.2 Selection of pests and diseases for analysis

Individual pests and diseases were not actively identified during the survey work for the project. In assessing the impact of pests and diseases, estimates of tree numbers were compared with the listed susceptible species for each pest or disease. Information was sourced from Defra's plant health portal and pests and diseases were selected for assessment based on their level of priority or concern. This included those that can lead to tree death or pose a significant human health risk; further details on individual pests and diseases are provided in Appendix IV. It is to be noted that this is not an exhaustive list of pests and diseases that may be present or have the potential to affect Belfast's urban forest should they enter into the UK. The information contained within Table 9 could be used to inform programmes to monitor the presence and spread of a pest or disease, and strategies to manage the risks that they pose.

5.3 Management to reduce this risk

Increasing the resilience of the urban forest as a whole by increasing tree species diversity may reduce the impact associated with some pests and diseases. Providing a greater diversity of tree species can increase the likelihood that more trees will not be susceptible to certain pests and diseases. Continuous monitoring of urban trees for signs of pests and diseases is key to their protection; ensuring this is built into seasonal survey work can lead to a quicker response time to the eradication of the pathogen before it becomes a problem.

5.4 Recommendations for Pests and Diseases

13. Establish a tree monitoring programme to give early warning of pests, diseases, and threats to Belfast's trees. This could be in the form of a community engagement and involvement opportunity.

14. Develop a Tree Warden scheme to include pest and disease monitoring or initiate a citizen science training and monitoring programme through 'observatree'.

15. As mentioned earlier in Chapter 3.6, When trees are removed, or new trees planted, choose replacements which increase species diversity.

16. Use the Right Trees for Changing Climate database, the TDAG species selection guide, and the Climate Matching Tool in conjunction with the Ecological Site Classification tree selection tool to find species that are likely to thrive in Belfast's future climate.

17. Plan for replacement of trees that will eventually be lost to Chalara dieback of ash (*Hymenoscyphus fraxineus*). Consider planting species that can reach large stature in maturity so that the benefits currently provided by these trees will be replaced.

18. Adopt best practice guidelines for plant biosecurity to minimise the likelihood of introducing pests and diseases through plant and plant material imports.

19. Healthy trees are more resilient to pests and diseases. Plant trees using best practice, focus on establishment, and ensure good aftercare to maintain healthy trees.

20. Establish an Internet of Things network of soil moisture sensors to determine whether young trees require watering.

21. Encourage community care (particularly watering) of young trees through communication, campaigns, signage, and QR codes.

22. Review ground management practices such as mowing and strimming, which create wounds through which pests and diseases can enter trees or, even, lead to ring-barking and the death of the tree. Consider mulching round trees to prevent grass and weed growth, retain moisture, and provide nutrition to the soil.

6. Replacement Cost

In addition to estimating the environmental benefits provided by trees, Eco also provides a structural valuation. In the UK this is termed the 'Replacement Cost'. It must be stressed that the way in which this value is calculated means that it does not constitute a benefit provided by the trees. The valuation is a depreciated replacement cost, based on the Council of Tree and Landscape Appraisers (CTLA) formulae.[28]

Replacement Cost is intended to provide a useful management tool, as it is able to value what it might cost to replace any or all of the trees (taking account of species suitability, depreciation and other economic considerations) should they become damaged or diseased for instance. The replacement costs for the ten most valuable tree species across Belfast's urban forest are shown in Figure 12 (below).

The total replacement cost of all trees in the study area, as estimated by Eco, currently stands at over £973 million.

[28] Hollis, 2007

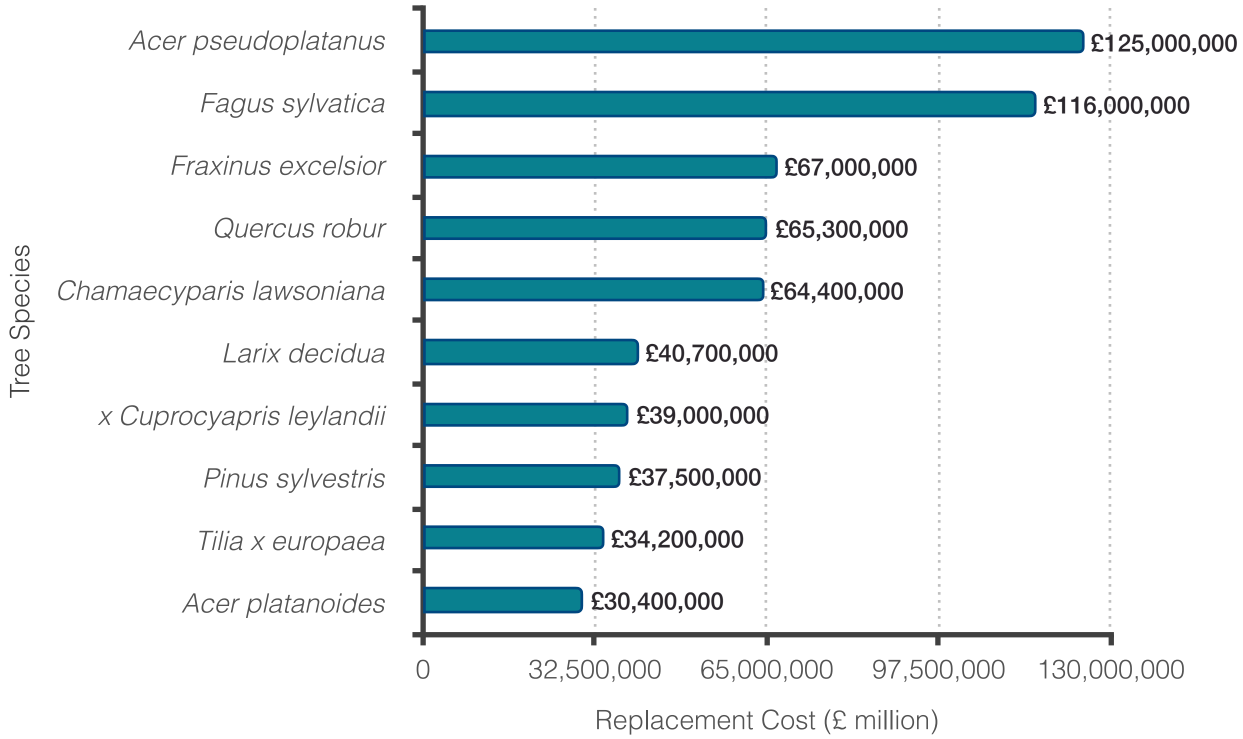

Figure 12: Replacement Cost for Top Ten Tree Species in Belfast

Trees in the Acer genus are the most valuable in total in Belfast, followed by *Fagus* and *Fraxinus*. These three genera alone have a replacement cost of **£309,000,000** (32%) of the total replacement cost of the trees in Belfast's urban forest, with the species *Acer psuedoplatanus* (Sycamore) alone accounting for 13% of the total replacement cost at over £125 million. A full list of trees with the associated replacement cost is given in Appendix III.

There are an estimated 535,000 trees in the urban stratum of Belfast’s urban forest making up 66% of Belfast’s urban forests tree total. The total replacement cost for these trees according to Eco is over £692 million.

There are an estimated 274,000 trees in the rural stratum of Belfast’s urban forest making up 34% of Belfast’s urban forests tree total. The total replacement cost for these trees according to Eco is just under £281 million.

7. CAVAT - The amenity value of trees

Capital Asset Valuation of Amenity Trees (CAVAT) is a method developed in the UK to provide a value for the public amenity that trees provide (Doick et al., 2018). CAVAT is designed for use with amenity trees in urban areas.

Measurements of the tree's stem diameter, crown size, crown condition and life expectancy are used to calculate the CAVAT value using an amended Quick Method (see Appendix IV for details). Only trees in the urban stratum were included in the calculation. Table 10 (below) gives CAVAT values (extrapolated across the whole study area) for the ten most valuable species.

For the urban forest of Belfast, the estimated total public amenity asset value is estimated to be £4,640,000,000.

Acer pseudoplatanus (Sycamore) holds the highest CAVAT value of all species in the study and represents 6% of the tree population in the urban area.

The most common species of tree in Belfast's urban forest is *Fraxinus excelsior* (ash), 10% of the population in the urban area). The average condition of ash trees surveyed in the urban area was 65%, while the average condition of sycamores surveyed in the urban area was 86%, resulting in their high public amenity value.

The tree with the single highest amenity value is a common beech in the grounds of Queen's University Belfast, with a CAVAT value of £158,000. The tree is in a woodland, has a stem diameter of over 100 cm, and is in good condition. However this tree was noted to have a fungal fruiting body on the main stem, resulting in a life expectancy reduced to between 40 and 80 years.

Species	CAVAT Value	Percent of Total Population	Replacement Cost
Acer pseudoplatanus (Sycamore)	£610,000,000	5.7%	£17,000,000
Fagus sylvatica (Beech)	£517,000,000	3.2%	£20,000,000
Chamaecyparis lawsoniana (Lawson's cypress)	£371,000,000	5.7%	£12,900,000
Tilia x europaea (Lime)	£294,000,000	2.3%	£16,100,000
Pinus sylvestris (Scots pine)	£284,000,000	5.3%	£10,400,000
Cupressus macrocarpa (Monterey cypress)	£260,000,000	0.6%	£8,360,000
Quercus robur (English oak)	£246,000,000	4.0%	£12,600,000
Fraxinus excelsior (Ash)	£243,000,000	9.7%	£8,670,000
x Cuprocyapris leylandii (Leyland cypress)	£184,000,000	4.8%	£5,950,000
Populus nigra (Hybrid black poplar**)**	£164,000,000	1.1%	£5,530,000
All other species	**£1,470,000,000**	**42.4%**	**£54,500,000**
Total	**£4,640,000,000**	**100%**	**£172,000,000**

Table 10: The Ten Species with the Highest CAVAT Valuation

Figure 13 shows CAVAT values of Belfast's urban trees by land use. Trees on residential land have the highest CAVAT value. The number of trees on each land use is the dominant factor in determining the total CAVAT value for each land use. For example, 38% of the trees surveyed in the urban area were on residential land.

Just 2% of the trees surveyed in the urban area were on multi-family residential land use sites (10 trees in total), resulting in a relatively low CAVAT value. These results suggest that there is scope to increase amenity provided by trees on multi-family residential land by increasing planting.

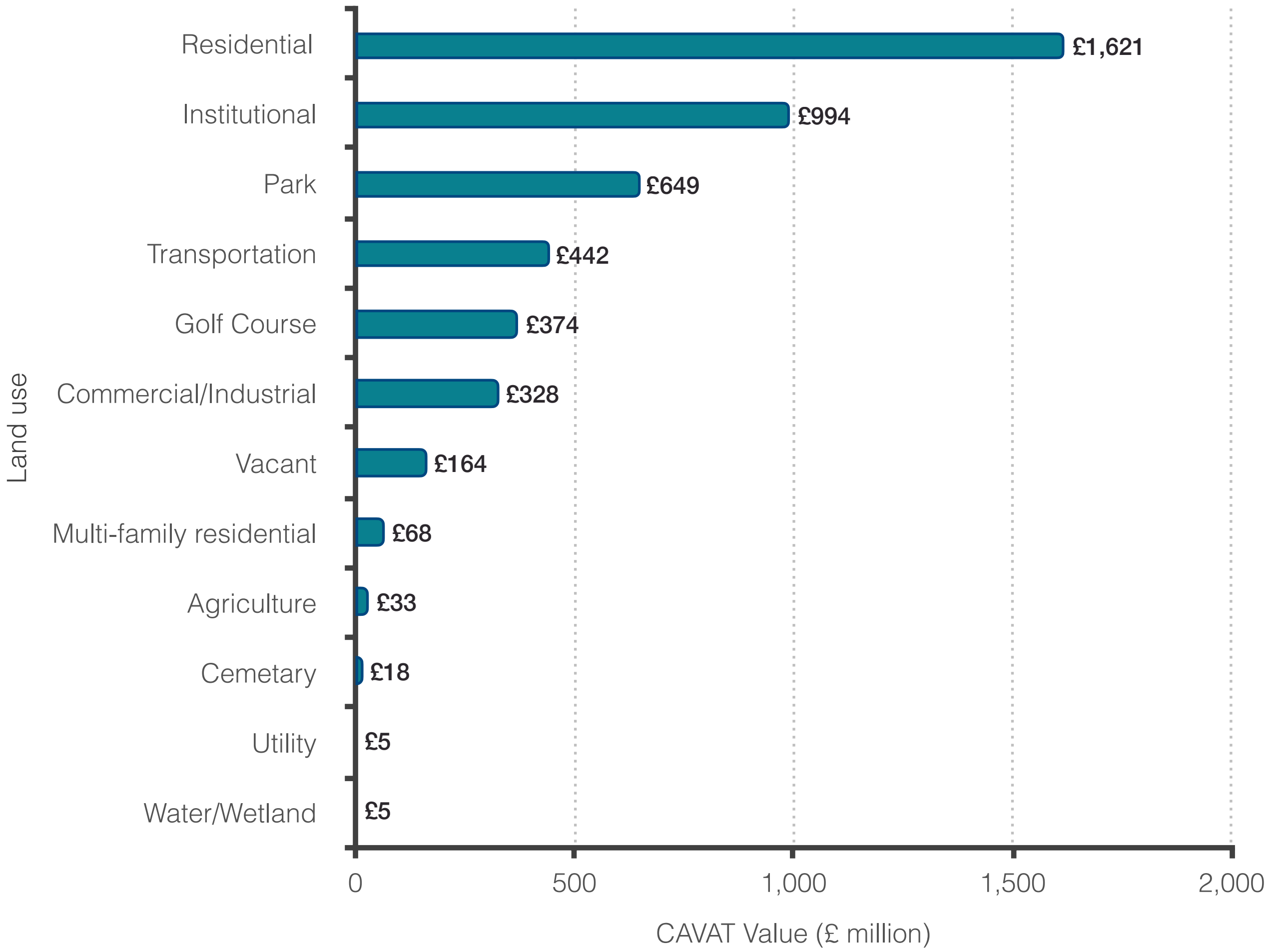

Figure 13: CAVAT values of trees in land uses (extrapolated across whole study area).

For more information about the CTLA method, and the differences between CTLA and CAVAT, see the CAVAT section of Appendix VI.

8. Conclusions

The tree population within Belfast's urban forest has a good species diversity, with 83 species identified. It is acknowledged that there are a number of constraints on urban and highway planting that can hinder planting of larger-growing species. The role of Belfast's trees in complementing people's health is clear, through air pollution removal especially.

Belfast's urban forest's trees provide a valuable benefit of over £16,100,000 in ecosystem services each year.

The most common species is *Fraxinus excelsior* (ash) accounting for 11.2% of the total population, which is significantly more than any other species, and indicates a reliance on this species which may reduce the resilience of Belfast's urban forest especially when considering ash dieback. The top 10 most common species account for 53% of all trees, store 60% of the total amount of carbon, sequester 5,130 tonnes of carbon each year and reduce the city's surface runoff by 189,954 m^3 each year worth £355,000 in avoided sewerage charges.

Like many urban areas, Belfast's urban forest would benefit from having a greater proportion of larger trees, and improved species diversity and balance in order to continue deliver greater benefit and promote structural diversity in its tree population. Larger-growing trees are important because they can provide greater canopy cover and therefore ecosystem service provision. They also tend to have higher amenity value than their smaller counterparts.

The values presented in this study should be seen as conservative estimates, only a proportion of the total potential benefits have been evaluated. Trees confer many benefits which have not been valued as part of this report, such as contributions to our health and well-being, reducing urban temperatures, providing amenity value and habitats for wildlife.[29]

The extent of these benefits needs to be recognised. Strategies and policies that will conserve this important resource (through education for example) would be one way to address this. Targets to increase canopy cover including planting larger trees, protecting large and veteran trees and, where possible, continue to diversify the urban forest through planting climate adaptable species should also be investigated through the production of an 'Urban Forest Masterplan'. Introducing and enforcing policies regarding the incorporation of green infrastructure in planning and design would go a long way to helping ensure trees reach their full potential in the urban environment. As the amount of healthy leaf area equates directly to the provision of benefits, consistent and considered management of the tree stock is important to ensure canopy cover levels continue to be maintained or increased. New tree planting can contribute to the growth of canopy cover. However, the most effective strategy for increasing average tree size and the extent of tree canopy is to adopt a management approach that enables a sustainable, healthy, age and species diverse tree population. This means that protecting existing tree stock is vital, and planning for tree growth must be taken into account before planting, to ensure the trees can remain a long-term, nature based solution to the challenges ahead.

Climate change could affect the tree stock in Belfast's urban forest in a variety of ways and there are great uncertainties about how this may manifest. Some species may be less able to survive under new climatic conditions. New climatic conditions may also allow new and present pests and diseases to become prevalent or to change their behaviours. Further studies into this area would be useful in informing any long-term tree strategies or urban forest masterplans, that carefully consider species selection.

[29] Davies *et al*, 2017

The challenge now is to ensure that policy makers and practitioners take full account of Belfast's trees in decision making. Not only are trees a valuable functional component of our landscape, they also make a significant contribution to people's quality of life. Incorporating the urban forest and green infrastructure int planning and design from the outset is vital to ensuring that Belfast can make the most of its space and maximise the benefits of trees for generations to come.

8.1 Final Recommendations

23. Undertake a ward-by-ward canopy cover assessment of the city to highlight areas that need more tree canopy cover.

24. Consider the equity of how trees and the benefits they provide are distributed across the city. Increase planting (and therefore benefit provision) in areas that are lacking in canopy cover. Look to plant in areas with high deprivation and those which experience high pollution, surface flooding, limited greenspace, or lack of shade.

25. As well as planting trees for carbon storage and sequestration, consider the other benefits that trees provide. Consider using Forest Research's "replacement rates" workbook to select tree species for provision of multiple benefits: Selecting urban trees for ecosystem service provision - Forest Research.

26. Large trees provide the most benefits. Retain large, mature trees wherever possible. Make them part of developments rather than lose them.

27. Use CAVAT to highlight amenity values of threatened trees to developers and communities, and to leverage compensation or sufficient replacement planting for amenity trees that are removed by developers. TDAG's new guide to delivering trees in planning and development contains recommendations for ensuring that the value

of trees is recognised and reflected in new developments: [Trees in Hard Landscapes: A Guide for Delivery - Trees and Design Action Group (tdag.org.uk)].

28. Set up community tree care schemes to encourage engagement by local people and help to ensure the good health of young trees.

29. Protect and enhance tree cover on private land (private gardens, commercial, industrial) by engagement with local community and businesses.

30. Find long-term uses for felled or dead trees, such as standing deadwood, sculptures and carvings, street and park furniture, or seasoning as native hardwood for sale. Chip or season for firewood only if there is no other use for the timber, so that the carbon is stored for as long as possible.

9. Appendices

Appendix I. Relative Tree Effects

The urban forest of Belfast provides benefits that include carbon storage and sequestration, air pollutant removal and reducing surface runoff. To estimate the relative value of these benefits, tree benefits were compared to estimates of average carbon emissions and average family car emissions. These figures should be treated as a guideline only as they are largely based on US values (see footnotes).

Carbon storage is equivalent to:

- Amount of carbon emitted in Belfast in 38 days
- Annual carbon (C) emissions from 248,000 automobiles
- Annual C emissions from 102,000 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 16 automobiles
- Annual carbon monoxide emissions from 43 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 11,900 automobiles
- Annual nitrogen dioxide emissions from 5,380 single-family houses

Sulfur dioxide removal is equivalent to:

- Annual sulfur dioxide emissions from 37,800 automobiles
- Annual sulfur dioxide emissions from 100 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Belfast in 1.1 days
- Annual C emissions from 6,900 automobiles
- Annual C emissions from 2,800 single-family houses

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (Carbon Dioxide Information Analysis Center 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

Light duty vehicle emission rates (g/mi) for CO, NO_x, VOCs, PM, SO_2 for 2010 (Bureau of Transportation Statistics 2010; Heirigs et al 2004), PM2.5for 2011-2015 (California Air Resources Board 2013), and CO_2 for 2011 (U.S. Environmental Protection Agency 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.

Household emissions are based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household in 2009 (Energy Information Administration 2013; Energy Information Administration 2014)

- CO_2, SO_2, and NO_x power plant emission per KWh are from Leonardo Academy 2011. CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on Energy Information Administration 1994. PM emission per kWh from Layton 2004.
- CO_2, NO_x, SO_2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Leonardo Academy 2011.
- CO_2 emissions per Btu of wood from Energy Information Administration 2014.
- CO, NO_x and SO_2 emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry 2005; Georgia Forestry Commission 2009).

Oxygen production figures are based on the total oxygen produced by the trees within Belfast's urban forest divided by the average intake of oxygen for each person per year - https://ntrs.nasa.gov/search.jsp?R=20060005209

Appendix II. Species Dominance Value List

Species	Percent Population	Percent Leaf Area	Dominance Value
Acer pseudoplatanus	9.2	16.9	26.0
Fagus sylvatica	5.4	15.0	20.4
Fraxinus excelsior	11.2	8.8	20.0
Quercus robur	4.5	4.3	8.8
Pinus sylvestris	3.8	3.7	7.5
Prunus avium	4.7	2.4	7.1
Larix decidua	4.0	2.6	6.6
Chamaecyparis lawsoniana	3.8	2.5	6.3
Tilia x europaea	1.5	4.2	5.8
x Cuprocyapris leylandii	3.2	2.2	5.4
Betula pendula	3.1	2.0	5.2
Alnus glutinosa	2.4	2.5	4.9
Acer platanoides	2.3	2.6	4.9
Crataegus monogyna	3.2	1.3	4.6
Alnus incana	2.1	1.7	3.8
Aesculus hippocastanum	0.8	2.8	3.6
Betula utilis	2.5	0.9	3.4
Tilia cordata	1.0	2.2	3.2
Pinus contorta	2.5	0.7	3.2
Alnus cordata	1.4	1.5	2.9
Cupressus macrocarpa	0.4	1.9	2.3
Ulmus glabra	1.0	1.2	2.3
Sorbus aucuparia	1.9	0.3	2.2
Populus nigra	0.8	1.3	2.1
Populus alba	0.7	1.4	2.1
Salix caprea	1.3	0.6	1.9
Salix cinerea	1.2	0.5	1.8
Sorbus aria	1.2	0.4	1.6
Ilex aquifolium	1.4	0.2	1.6
Corylus avellana	0.8	0.7	1.5
Taxus baccata	0.9	0.6	1.5

Species	Percent Population	Percent Leaf Area	Dominance Value
Macromeles tschonoskii	1.1	0.2	1.4
Carpinus betulus	0.5	0.8	1.3
Quercus petraea	0.8	0.4	1.2
Prunus laurocerasus	1.0	0.2	1.2
Acer campestre	1.0	0.2	1.2
Prunus domestica	0.7	0.3	1.0
Sorbus intermedia	0.4	0.6	1.0
Magnolia	0.7	0.2	0.9
Quercus rubra	0.4	0.5	0.8
Salix babylonica	0.1	0.6	0.8
Fraxinus	0.1	0.6	0.7
Metasequoia glyptostroboides	0.4	0.4	0.7
Aesculus indica	0.1	0.5	0.7
Tilia platyphyllos	0.1	0.5	0.7
Platanus acerifolia	0.1	0.5	0.6
Acer palmatum	0.4	0.2	0.6
Taxus baccata 'Fastigiata'	0.3	0.3	0.6
Sambucus nigra	0.6	0.1	0.6
Elaeagnus	0.4	0.2	0.6
Picea abies	0.3	0.2	0.5
Malus domestica	0.4	0.1	0.5
Juniperus communis	0.4	0.1	0.5
Prunus padus	0.3	0.2	0.5
Salix fragilis	0.4	<0.01	0.4
Malus	0.3	0.1	0.4
Malus sylvestris	0.3	0.1	0.4
Prunus serrulata	0.3	0.1	0.4
Acer platanoides 'Crimson King'	0.3	0.1	0.4
Betula pubescens	0.1	0.2	0.3
Laburnum alpinum	0.3	<0.01	0.3
Ulmus procera	0.1	0.2	0.3
Olea europaea	0.3	0.0	0.3
Laurus nobilis	0.1	0.1	0.3
Ligustrum ovalifolium	0.1	0.1	0.3

Species	Percent Population	Percent Leaf Area	Dominance Value
Fagus sylvatica 'Purpurea'	0.1	0.1	0.3
Cercidiphyllum japonicum	0.1	0.1	0.2
Cupressus	0.1	0.1	0.2
Cedrus atlantica v. glauca	0.1	0.1	0.2
Ulmus	0.1	0.1	0.2
Pittosporum	0.1	<0.01	0.2
Sambucus	0.1	<0.01	0.2
Juniperus	0.1	<0.01	0.1
Prunus lusitanica	0.1	<0.01	0.1
Prunus pissardii	0.1	<0.01	0.1
Laburnum	0.1	<0.01	0.1
Pyracantha	0.1	<0.01	0.1
Betula	0.1	<0.01	0.1
Cordyline australis	0.1	<0.01	0.1
Trachycarpus fortunei	0.1	<0.01	0.1
Cordyline	0.1	<0.01	0.1
Prunus cerasifera 'Nigra'	0.1	<0.01	0.1
Eucalyptus	0.1	<0.01	0.1

Appendix III. Ecosystem Service provision and Replacement Cost by Species

Species	Trees	Carbon Storage (tonnes)	Gross Carbon Seq (tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (tonnes/ Yr)	Replacement Cost (£)
Acer pseudoplatanus	74076	48176	1155	53516	21.0	£125,030,616
Fagus sylvatica	43558	43520	450	47712	18.7	£116,436,054
Fraxinus excelsior	90495	18607	869	28015	11.0	£67,040,864
Quercus robur	36277	15620	538	13761	5.4	£65,332,249
Chamaecyparis lawsoniana	30387	15412	287	7949	3.1	£64,402,989
Larix decidua	32436	11377	314	8252	3.2	£40,717,941
x Cuprocyapris leylandii	25885	18616	771	7082	2.8	£39,043,138
Pinus sylvestris	31115	6448	290	11726	4.6	£37,477,283
Tilia x europaea	12380	19122	399	13437	5.3	£34,181,042
Acer platanoides	18470	7248	304	8222	3.2	£30,386,683
Cupressus macrocarpa	3376	9009	2	6106	2.4	£22,576,638
Prunus avium	38133	8382	298	7664	3.0	£21,821,885
Ilex aquifolium	11254	3947	39	623	0.2	£20,128,764
Tilia cordata	7878	4624	123	7010	2.8	£18,693,786
Aesculus hippocastanum	6488	13576	168	8901	3.5	£17,290,835
Alnus glutinosa	19661	1432	72	7983	3.1	£17,138,279
Pinus contorta	20123	2574	104	2176	0.9	£15,632,135
Crataegus monogyna	26016	5206	155	4278	1.7	£15,212,927
Betula pendula	25288	3248	250	6452	2.5	£13,591,822
Populus nigra	6620	4790	262	4221	1.7	£11,226,847
Alnus cordata	11254	2453	80	4726	1.9	£10,089,308
Taxus baccata 'Fastigiata'	2251	3164	3	1090	0.4	£9,312,847
Betula utilis	20456	1132	133	2868	1.1	£9,246,136
Alnus incana	16882	748	32	5390	2.1	£9,002,855
Populus alba	5495	2508	118	4527	1.8	£7,516,332
Sorbus aria	9997	1628	71	1304	0.5	£7,447,422
Salix cinerea	9997	4236	157	1681	0.7	£7,248,160

Species	Trees	Carbon Storage (tonnes)	Gross Carbon Seq (tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (tonnes/ Yr)	Replacement Cost (£)
Taxus baccata	7083	1527	35	1907	0.8	£7,246,560
Ulmus glabra	8473	2275	103	3935	1.5	£7,142,510
Malus	2251	2484	21	391	0.2	£6,632,211
Platanus acerifolia	1125	2951	105	1613	0.6	£6,073,983
Prunus domestica	5627	2064	39	988	0.4	£5,997,142
Carpinus betulus	4369	1468	28	2431	1.0	£5,011,828
Sorbus aucuparia	15624	1023	120	958	0.4	£4,950,342
Metasequoia glyptostroboides	2979	535	20	1183	0.5	£4,745,636
Corylus avellana	6355	1050	34	2243	0.9	£4,344,080
Sorbus intermedia	3244	4441	31	1913	0.8	£4,183,427
Macromeles tschonoskii	9004	1167	96	763	0.3	£4,169,283
Prunus laurocerasus	7878	867	84	705	0.3	£4,063,176
Salix caprea	10857	689	60	1839	0.7	£3,621,661
Aesculus indica	1125	969	1	1732	0.7	£3,339,215
Magnolia	5495	450	38	550	0.2	£2,934,331
Quercus petraea	6090	485	24	1421	0.6	£2,850,238
Quercus rubra	2979	683	29	1520	0.6	£2,647,533
Acer campestre	7878	147	27	629	0.3	£2,292,852
Ulmus procera	1125	690	28	494	0.2	£2,288,494
Picea abies	2251	427	14	780	0.3	£2,163,500
Laurus nobilis	1125	3144	31	408	0.2	£2,159,785
Acer palmatum	3376	235	14	649	0.3	£2,156,295
Tilia platyphyllos	1125	2553	11	1656	0.7	£2,150,326
Fagus sylvatica 'Purpurea'	1125	363	15	376	0.2	£1,626,153
Juniperus communis	3376	199	13	186	0.1	£1,578,739
Prunus serrulata	2118	860	16	313	0.1	£1,532,634
Elaeagnus	2979	385	29	731	0.3	£1,504,940
Salix babylonica	1125	1101	77	2040	0.8	£1,498,274
Prunus padus	2118	655	26	600	0.2	£1,448,759
Sambucus nigra	4502	226	13	165	0.1	£1,394,326

Species	Trees	Carbon Storage (tonnes)	Gross Carbon Seq (tonnes/ Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (tonnes/ Yr)	Replacement Cost (£)
Malus domestica	3376	100	23	320	0.1	£1,213,809
Malus sylvestris	2251	145	21	319	0.1	£1,106,245
Laburnum alpinum	2251	161	15	67	<0.01	£1,043,016
Cordyline	1125	25	5	13	<0.01	£958,749
Fraxinus	993	540	25	1977	0.8	£939,345
Ligustrum ovalifolium	1125	316	12	406	0.2	£907,192
Betula pubescens	1125	125	8	655	0.3	£907,167
Salix fragilis	2979	63	10	153	0.1	£888,474
Cordyline australis	1125	61	10	14	<0.01	£872,932
Prunus pissardii	1125	293	13	25	<0.01	£810,336
Ulmus	1125	179	12	202	0.1	£715,659
Cercidiphyllum japonicum	993	58	3	370	0.2	£709,288
Eucalyptus	1125	209	3	1	<0.01	£594,191
Acer platanoides 'Crimson King'	2251	101	16	254	0.1	£584,974
Cupressus	1125	197	16	308	0.1	£491,162
Pittosporum	1125	96	9	56	<0.01	£458,888
Pyracantha	1125	48	7	21	<0.01	£431,359
Sambucus	1125	36	8	36	<0.01	£426,386
Juniperus	1125	74	7	33	<0.01	£407,055
Trachycarpus fortunei	1125	39	3	13	<0.01	£402,334
Cedrus atlantica v. glauca	1125	2656	17	282	0.1	£384,372
Olea europaea	2251	28	6	20	<0.01	£375,069
Betula	1125	31	10	18	<0.01	£273,205
Prunus lusitanica	1125	18	3	27	<0.01	£113,609
Laburnum	1125	11	2	23	<0.01	£95,135
Prunus cerasifera 'Nigra'	1125	100	1	4	<0.01	£69,021
Total	**808624**	**318626**	**8893**	**317405**	**124.3**	**£973,153,039**

Appendix IV. The relative benefits and interactions of trees and other natural systems for carbon storage and sequestration

Habitat and component	Carbon storage / tonnes C per hectare	Carbon sequestration / tonnes C per hectare per year	References
Urban soil	145	-	Edmondson et al, 2012.
Woodland soil	66 - 131	0 - 0.5	De Vries et al., 2003; Carey et al., 2008; Gregg et al., 2012.
Woodland trees	22 - 244	2 - 4	Gregg et al., 2021.
Trees outside woodland	10 - 150	1 - 3	This study; Sparrow & Doick, Forest Research,. unpublished; Nowak et al., 2013; Strohbach et al., 2012.
Grassland soil	48 - 195	1*	Carey et al., 2008; Lindén et al., 2020; Poeplau et al., 2016; Warner et al., 2020.
Grassland vegetation	1	0.5*	Dawson et al., 2007; Warner et al., 2020.
Green roof substrate and vegetation	13 - 644	4 - 125	Getter et al., 2009; Whittinghill et al., 2014; Sultana et al., 2020.

Table 11: Carbon storage and sequestration by soil and vegetation commonly found in UK urban areas.

*This is not an exhaustive review of literature; the figures to enable indict

Appendix V. Pests and Disease

Acute oak decline

Acute oak decline (AOD) is caused by multiple agents, especially bacteria. It mainly affects mature trees (>50 years old) of both native oak species *(Quercus robur and Q. petraea)*, but symptoms have also been identified on younger oaks and additional species, including *Q. cerris* and *Q. fabrei.* Some affected trees can die in as little as 4–6 years after symptoms have developed. Over the past few years, the reported incidents of stem bleeding and exit holes of the associated beetle *Agrilus biguttatus*, indicating potential AOD infection, have been increasing. The condition is most prevalent in a band across the Midlands of English from East Anglia to the Welsh Borders. It has not been reported in Scotland or Northern Ireland. If AOD were to spread to Northern Ireland, it would pose a threat to 6% of Belfast's urban forest.

Ash sawfly

Ash sawfly *(Tomostethus nigritus)* is a relatively new species to Ireland. It is native to Great Britain and continental Europe, where it causes sporadic damage. It was first recorded on the island of Ireland in a suburban housing estate in Belfast in 2016[30] and has since spread to the Republic of Ireland.[31] Caterpillars of the ash sawfly feed on the leaves of ash trees *(Fraxinus excelsior and F. angustifolia)* and can completely defoliate a plant between spring and mid-summer. Affected trees survive the attack and grow new leaves in summer but it is likely that repeated defoliation year after year reduces the vigour of the trees. No control measures are currently available, and little is known about the cause of the impacts, or why they are more severe in some locations than others. Synchronicity between the life cycle of the sawfly and flushing of leaves on ash trees of different species or in different microclimates may account for some of the

[30] Jess et al., 2017

[31] Soldi et al., 2022

variation.[32] It is thought that adult sawflies can be transported on people and vehicles.[33] ash sawfly threatens 11.3% of Belfast's trees.

Asian longhorn beetle

The Asian longhorn beetle *(Anoplophlora glabripennis)* is a major pest in China, Japan and Korea, where it kills many broadleaved species. There are established populations of Asian longhorn beetle (ALB) in parts of North America and there have been outbreaks in Europe. Where the damage to street trees is high, felling, sanitation and quarantine are the only viable management options.

In March 2012 an ALB outbreak was found in Maidstone, Kent, England. The Forestry Commission and Fera removed more than 2,000 trees from the area to contain the outbreak. The main risk of another outbreak comes from untreated wood packaging material from China, as in 2012. No further outbreaks have been reported in the UK. Climate suitability modelling suggests that Belfast's climate may be suitable for the survival of the beetle.[34] If an ALB outbreak did occur in Northern Ireland it would pose a significant thread to 62% of Belfast's trees, not including attacks on shrub species. The known host species include:

- *Acer spp.* (maples and sycamores)
- *Aesculus spp.* (horse chestnut)
- *Albizia julibrissin* (Mimosa silk tree)
- *Alnus spp.* (alder)
- *Betula spp.* (birch)
- *Carpinus spp.* (hornbeam)
- *Cercidiphyllum japonicum* (Katsura tree)
- *Corylus spp.* (hazel)
- *Fagus spp.* (beech)
- *Fraxinus spp.* (ash)
- *Koelreuteria paniculata* (Golden rain tree)
- *Malus spp.* (apple)
- *Platanus spp.* (plane)
- *Populus spp.* (poplar)

[32] Verheyde and Sioen., 2019

[33] Soldi et al., 2022

[34] MacLeod, Evans & Baker, 2002

- *Prunus spp.* (cherry, plum)
- *Pyrus spp.* (pear)
- *Robinia pseudoacacia* (false acacia/black locust)
- *Salix spp.* (willow, sallow)
- *Sorbus spp.* (rowan, whitebeam etc)
- *Styphnolobium japonicum* (Japanese pagoda tree)
- *Quercus palustris* (American pin oak)
- *Quercus rubra* (North American red oak)
- *Ulmus spp.* (elm).

Bronze birch borer

The Bronze birch borer *(Agrilus anxius)* is a wood-boring beetle that feeds on the inner bark and cambium of birch trees. The disruption to water and nutrient flow that occurs as a result means that trees can die within a few years after symptoms appear. At current, the Bronze birch borer is present across North America, including the United States, where it is native, and Canada. Bronze birch borer has caused extensive mortality of *Betula spp*. planted as street and ornamental trees in towns and cities, due to its ability to colonize most birch species and cultivars. If it were to be introduced to the UK, and specifically to Northern Ireland, 6% of Belfast's urban forest could be at risk.

Chalara dieback of ash

ashdieback, caused by the fungus *Hymenoscyphus fraxineus,* is a highly destructive disease of ashtrees, including *Fraxinus excelsior, F. excelsior 'Pendula' and F. angustifolia.* Young trees are particularly susceptible and can be killed within one growing season of symptoms becoming visible. Older trees can take longer to succumb, but can die from the infection or secondary pathogens (e.g. *Armillaria*) after several seasons. ashdieback has been widely reported across the UK, including in urban areas. *H. fraxineus* was first recorded in Northern Ireland in 2012 on recentlyplanted ashtrees. By 2016 over 170 infection sites had been confirmed. Chalara ashdieback poses a threat to 11% of Belfast's urban forest.

Emerald ash borer

Emerald ash borer (EAB) is likely to have a major impact on our already vulnerable ash population in the UK if established. There is no evidence to date that EAB is present in the UK, but the increase in global movement of imported wood and wood packaging heightens the risk of its accidental introduction. EAB is present in Russia and Ukraine and is moving West and South at a rate of 30-40 km per year, perhaps aided by vehicles.[35] EAB has had a devastating effect in the USA due to its accidental introduction and could add to pressures already imposed on ash trees from diseases such as Chalara dieback of ash. Emerald ash borer poses a potential future threat to 13% of Belfast's urban forest.

Ips typographus

Ips typographus is the Larger eight-toothed European spruce bark beetle. It is a destructive pest of spruce trees (trees in the genus *Picea*) as well as some species in other conifer genera. *Ips typographus* is present in spruce trees in most of continental Europe, as well as China, Japan, North and South Korea, and Tajikistan. An outbreak was discovered in Kent, England in 2018 and is being eradicated. Subsequent monitoring has found outbreaks in Kent and East Sussex, England, and these are also being controlled. It is likely that beetles were blown into the area from mainland Europe. They can also be spread in movements of infested timber or firewood. The beetle prefers weak, dead or dying trees but large populations can spread to health trees. It is primarily a threat to Sitka spruce *(Picea stichensis)* plantations. If introduced to Northern Ireland *Ips typographus* could threaten 7% of Belfast's trees.

[35] Straw et al., 2013

Oak processionary moth

Oak processionary moth (OPM) was accidentally introduced to Britain in 2005 and there are now established OPM populations in most of Greater London and in some surrounding counties. It is thought that OPM has been spread through imported nursery trees and it has been estimated that OPM could survive and breed in the Belfast area in the current climate and in predicted future climate scenarios.[36] The caterpillars cause serious defoliation of oak trees, their principal host, which can leave them more vulnerable to other stresses. The caterpillars have urticating (irritating) hairs that can 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 in recent years. Whilst the outbreak in London is beyond eradicating, the rest of the UK maintains its European Union Protected Zone status (PZ) and restrictions on moving oak trees are in place to minimise the risk of further spread. Were it to be accidentally introduced to Northern Ireland, OPM would pose a threat to 6% of Belfast's urban forest.

Oak wilt

Oak wilt is a disease caused by the fungus *Ceratocystis fagacearum*. Oak wilt is present in the United States but there are no records of it being found elsewhere. It causes extensive damage, particularly to 'red oak' species such as *Quercus rubra* and *Q. palustris.* The UK and Ireland's native oak species *Quercus robur* and *Q. petraea*, as well as the European sweet chestnut *Castanea sativa*, are known to be susceptible to the fungus. The fungus spreads by itself underground, by movement of insects above ground, and can also be spread by transporting infected wood. If it were accidentally introduced to Norther Ireland, it has the potential to threaten 6% of Belfast's trees.

[36] Godefroid et al., 2020

Phytophthora lateralis

Phytophthora lateralis is a water mould, a fungus-like organism which infects the roots of trees that come into contact with spores in soil or water. It primarily infects Lawson cypress trees (*Chamaecyparis lawsoniana*), few of which recover from infection. P. lateralis is present in all four countries of the UK. In 2016 it was known to be present in approximately 20 locations in Northern Ireland, including Belfast. The fungus causes progressive damage eventually resulting in the death of large sections of the tree or of the whole tree. It poses a threat to 4% of the trees in Belfast's urban forest.

Phytophthora ramorum

Phytophthora ramorum is a water mould, a fungus-like organism that can attack a wide range of trees and other plants. The collective name for the diseases it causes are referred to as Ramorum disease. P. ramorum affects but is not limited to the following genera and species:

- *Abies alba*
- *A. grandis*
- *A. procera*
- *Acer pseudoplatanus*
- *Aesculus hippcastanum*
- *Betula pendula*
- *Castanea sativa*
- *Chamaecyparis lawsoniana*
- *Fagus sylvatica*
- *Fraxinus excelsior*
- *Ilex aquifolia*
- *Larix spp.*
- *Magnolia spp.*
- *Picea sitchensis*
- *Pseudotsuga menziesii*
- *Quercus cerris*
- *Q. ilex*
- *Q. petraea*
- *Q. robur*
- *Q. rubra*
- *Salix caprea*
- *Sequoia sempervirens*
- *Sorbus aucuparia*
- *Taxus baccata*
- *Tsuga heterophylla*

P. ramorum was first confirmed in Northern Ireland in rhododendron plants in a nusery in 2002. It was subsequently detected in a larch plantation in County Antrim in 2010. The pathogen can be spread on footwear, vehicles, tools and machinery, by the movement of infected plants, and in rain, mist and air. It is a particular problem for larch forests, with 1,000 hectares of larch trees affected in Northern Ireland and scheduled for felling. It has the potential to affect 36% of Belfast's urban forest.

Pine processionary moth

Caterpillars of the pine processionary moth (*Thaumetopoea pityocampa*) are a threat to the health of pine trees *(Pinus spp.)* and some other conifer species. Like Oak processionary moth, they also pose a hazard to human and animal health. Pine processionary moth is native to southern Europe, North Africa, and parts of the Middle East. It has spread north as far as Hungary, Switzerland, and France. It is not known to be present in the UK although it has occasionally been found in southern England. The climate of Northern Ireland is unlikely to be suitable for the caterpillar but it's northward spread is of concern. If it was introduced into Northern Ireland by import of plants or soil containing moths, eggs, caterpillars or pupae, it could pose a threat to 6% of Belfast's trees.

Xylella fastidiosa

Xylella fastidiosa is a bacterium that has the potential to cause significant damage to a range of broadleaf trees and commercially grown plants. The bacterium has been found in parts of Europe and can be spread through the movement of infected plant material and through insects from the Cicadellidae and Ceropidae families. There are four known subspecies: *Xylella fastidiosa subsp*. multiplex, *Xylella fastidiosa subsp. fastidiosa, Xylella fastidiosa subsp. pauca* and *Xylella fastidiosa subsp*. *Sandyi*. The subspecies multiplex is thought to be able to infect the widest variety of trees and plants, including *Quercus robur* and *Platanus occidentalis*. It is estimated that 15% of

Belfast's trees could be at risk of infection from X. fastidiosa subsp. multiplex, and if additional subspecies were to become prevalent in the area, this is likely to have a much wider impact, affecting ornamental and commercial shrubs and plants too.

For further information on the pests and diseases listed above, as well as other pathogens that pose a threat to the UK's trees, please take a look at the following resources:

- NI Plant Health Risk Register NI Plant Health Risk Register | Department of Agriculture, Environment and Rural Affairs: daera-ni.gov.uk

- Defra plant health portal UK Plant Health Information Portal - UK Plant Health Information Portal: defra.gov.uk

- Defra Plant health risk register UK Plant Health Risk Register: defra.gov.uk

- Forest Research Pest and disease resources pests and diseases resources and advice: Forest Research

- Forest Research "replacement rates" workbook: tree species selection for Ecosystem Services Selecting urban trees for ecosystem service provision: Forest Research

- TreeCheck About TreeCheck | Department of Agriculture, Environment and Rural Affairs: daera-ni.gov.uk

- Observatree An early warning system for tree health and tree disease : Observatree

- TreeAlert TreeAlert: Forest Research

- Current and future Climate Matching Tool Climate Matching Tool - Forest Research

- Ecological Site Classification tree selection tool Ecological Site Classification (ESC): Forest Research
- The Right Trees for Changing Climate database Right Trees For a Changing Climate: righttrees4cc.org.uk

- Trees and Design Action Group (TDAG) Tree Species Selection Guide Tree Species Selection for Green Infrastructure - Trees and Design Action Group: tdag.org.uk

Appendix VI. Notes on Methodology

i-Tree Methodology

i-Tree Eco is designed to use standardised field data and local hourly air pollution and meteorological data to quantify forest structure and its numerous effects, including:

- Forest structure (e.g., species composition, tree health, leaf area, etc.)
- Amount of pollution removed hourly by trees, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns).
- Total carbon stored and net carbon annually sequestered by trees
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration
- Potential impact of infestations by pests, such as Asian longhorned beetle, emerald ashborer, gypsy moth, and Dutch elm disease

To calculate 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.[37] To adjust for this difference, biomass results for open-grown urban trees were multiplied

[37] Nowak 1994

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.

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of trees account for decomposition.[38]

Recent updates (2011) to air quality modelling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values.

Air pollution removal estimates are derived from calculated hourly tree canopy resistances for ozone, sulphur dioxide and nitrogen dioxide based on a hybrid of big-leaf and multi-layer canopy deposition models.[39] 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[40,41] that were adjusted depending on leaf phenology and leaf

38 Nowak, David J., Hoehn, R., and Crane, D. 2007.

39 Baldocchi 1987, 1988

40 Bidwell and Fraser 1972

41 Lovett 1994

area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere.[42]

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. The value of avoided runoff is based on estimated or user-defined local values.

Replacement Costs were based on the valuation procedures of the Council of Tree and Landscape Appraisers, which use tree species, diameter, condition and location information[43,44].

For a full review of the model see UFORE (2010) and Nowak and Crane (2000).
For UK implementation see Rogers et al (2014).
Full citation details are located in the bibliography section.

[42] Zinke 1967

[43] Hollis, 2007

[44] Rogers et al (2012)

CTLA & CAVAT

Key differences between CTLA and CAVAT:

- The CTLA equation uses an actual price of the largest available transplantable replacement tree and adds to this a theoretical cost of the additional cross-sectional area required to reach the size of the subject tree.

- CAVAT does not take into account an actual price of a replacement tree, and instead multiplies the cross-sectional stem area of the subject tree by the Unit Value.

- Land use and species suitability are considered by this i-Tree Eco version of CTLA and not by the amended CAVAT version.

- Population density, crown size, and life expectancy are considered by the amended CAVAT version and not by the i-Tree Eco version of CTLA.

CTLA

Depreciated Replacement Cost (DRC) methodology is a way of estimating the current cost of replacing an asset (such as a tree) with a modern equivalent, less deductions for physical deterioration, obsolescence, and optimisation.[45] DRC is an appropriate valuation method when there is no comparative market-based price that represents the value of the asset, which is the case with trees.[46]

In i-Tree Eco, the replacement value of all trees in the study is calculated using the Council of Tree and Landscape Appraisers (CTLA) Trunk Formula Method (TFM). The

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45 RICS, 2018

46 RICS, 2018

CTLA is a North American consortium of "green" industry organisations.[47] The TFM is a DRC method commonly used in the United States as a measure of compensatory value, which can be thought of as the cost of replacing trees that have been lost, or the monetary settlement which could be paid to compensate for their damage, death or removal.[48]

The Trunk Formula Method (TFM) is suitable for trees that are too large to be replaced like-for-like. The compensatory value is calculated by multiplying a "basic value" by condition and location factors between 0 and 1[49]:

Compensatory Value = Basic Value × Condition factor × Location Factor

The basic value is determined by the replacement cost of a tree at the largest transplantable size, the cross-sectional areas of the stem of the subject tree (TA_A) and of the transplantable tree (TA_R), a basic price, and a species value[50]:

Basic Value = Replacement Cost + [Basic Price × (TA_A – TA_R) × Species Value]

Replacement Cost, Basic Price and Species Values are derived from the Royal Institute of Chartered Surveyors (RICS), and Barchams and Hilliers catalogues. Species Value takes into account the suitability of the tree species to the local environment.

Condition factors are based on crown dieback recorded during the survey (Nowak et al., 2002):

[47] Cullen, 2007

[48] Nowak et al., 2002

[49] Nowak et al., 2002

[50] Nowak et al., 2002

Crown Dieback	Condition rating	Condition factor
< 1%	Excellent	1
1–10%	Good	0.95
11–25%	Fair	0.82
26–50%	Poor	0.62
51–75%	Critical	0.37
76–99%	Dying	0.13
100%	Dead	0

Table 11: Condition Factors Based on Crown Dieback

i-Tree Eco takes a simplified approach to location factor, based on land use type recorded in the survey (Nowak et al., 2002):

Data	Value	Sou
Unit value	£16.26	CAVAT E
CTI factor	150%	CAVAT E
Crown size	Percent missing	i-Tree Ec
Crown condition	Percent condition	i-Tree Ec

Table 13: CAVAT Values and Sources

CAVAT

In addition and separate to the replacement value calculated within i-Tree Eco, we calculate an asset value of Belfast's trees using CAVAT (Capital Asset Value for

Percent of crown missing	Crown Size Factor
0%	1
1% - 20%	0.8
20% - 40%	0.6
40% - 60%	0.4
60% - 80%	0.2
80% - 100%	0

Table 14: Crown Size Factors

Amenity Trees). CAVAT is a DRC method developed in the UK (Doick et al., 2018) and is designed for use with urban amenity trees. Only trees in the urban stratum are included in the CAVAT calculation.

Like the CTLA method, CAVAT uses the cross-sectional area of the tree, and a unit

Crown % dieback	Crown Condition Factor
0%	1
1% - 20%	0.8
20% - 40%	0.6
40% - 60%	0.4
60% - 80%	0.2
80% - 100%	0

Table 15: Crown Condition Factors

value, to arrive at a theoretical cost of a replacement tree, and then decreases or increases that value to account for the individual characteristics of the subject tree. An amended CAVAT Quick method is used, as is appropriate to the range of information collected within an i-Tree Eco survey:

Land Use	Location factor
Golf course	**0.8**
Commercial/Industrial	**0.75**
Cemetery	**0.75**
Institutional	**0.75**
Parks	**0.6**
Residential	**0.6**
Transportation	**0.5**
Forest	**0.5**
Agriculture	**0.4**
Vacant	**0.2**
Wetland	**0.1**

Table 12: Land-Use Types and Location Factor

CAVAT value = Basic Value × CTI Factor × Crown Size Factor × Crown Condition

Life Expectancy	Life Expectancy Factor
0 years (dead)	0
<5 years	0.1
5 - <10 years	0.3
10 - <20 years	0.55
20 - <40 years	0.8
40 - <80 years	0.95
>80 years	1

Table 16: Life Expectancy Factors

Factor × Life Expectancy Factor

The Basic Value is determined by multiplying the cross-sectional stem area (TA) by the Unit Value, which is determined from UK nursery prices and an allowance for tree planting cost:

Basic Value = TA × Unit Value

The Community Tree Index (CTI) Factor takes into account the local population density, and appreciates (increases) the value for densely populated areas. For Belfast, this results in multiplication of the Basic Value by 1.5.

The Crown Size Factor is based on the percent of the crown missing, which is recorded during i-Tree Eco surveys:

The Crown Condition Factor is determined by the amount of dieback in the crown of the measured tree, which is recorded during i-Tree Eco surveys:

The Life Expectancy Factor is determined from the life expectancy of the tree recorded during the survey:

Details about the full CAVAT method are given in Doick et al. (2018).

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