Forest Research

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Valuing Wrexham's Urban Forest

Assessing the Ecosystem Services of Wrexham's Urban Trees: A Technical Report

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The Research Agency of the Forestry Commission

Forest Research is the Research Agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research. The Agency aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, technical support and consultancy services.

Treeconomics is a social enterprise, whose mission is to highlight the benefits of trees. Treeconomics works with businesses, communities, research organisations and public bodies to achieve this.

i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and community forestry analysis and benefits assessment tools. The Forest Service, Davey Tree Expert Company, National Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, and Casey Trees have entered into a cooperative partnership to further develop, disseminate and provide technical support for the suite.

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Summary

Urban forests are a valuable source of ecosystem services in towns and cities. They help us alleviate problems associated with densely packed populations by improving local air quality, capturing carbon and reducing flooding. They also provide food and habitat for animals, such as birds and bees, and improve social cohesion in communities.

However, the value of urban trees, both quantifiable and otherwise, is often overlooked within planning developments. By valuing the quantifiable services provided by trees in Wrexham County Borough, Wrexham County Borough Council and Natural Resources Wales can increase the profile of the County's urban forests, ensuring their value is maintained and improved upon. In addition, valuing these ecosystem services helps town planners, landscape architects and tree officers to plan where trees will be planted for the maximum benefit.

A survey of Wrexham County Boroughs trees' to value a number of ecosystem services was undertaken in summer 2013 with the aid of i-Tree Eco, used for the first time in Wales. i-Tree Eco is a model developed by the US Forest Service that allows scientists to measure a range of ecosystem services provided by urban trees, from carbon sequestration to pollutant removal. The study was funded by Natural Resources Wales and Wrexham County Borough Council and was carried out by Forest Research.

The quality of life for residents of Wrexham is significantly improved by its urban forest, helping alleviate flash flooding and sewer blockages, providing cleaner air and supporting wildlife such as pollinators. In addition, Wrexham's urban forest contributes significantly to the local economy, saving around £1.44 million in services per year. This would be enough money to plant nearly 800 medium sized oak trees in Wrexham and is comparable to the amount needed to refurbish Wrexham cemetery (Wrexham.com, 2014).

Wrexham has a high density of trees but low canopy cover compared to similar sized towns. A further 28% of Wrexham's urban space could be planted with trees, bringing Wrexham in line with other urban areas. Wrexham's urban forest could also be improved by planting a higher diversity of tree species, improving its resilience to pests and diseases.

The number of large trees in Wrexham is above average for the UK and, in particular, there are many impressive old oaks. However, there are fewer large trees than recommended for a future-proofed urban forest, suggesting some room for improvement. Increasing planting of large stature trees may future proof Wrexham's impressive stock of large growing trees.

A summary of key results is presented on page 5.

Key Results

The **ecosystem services** provided by Wrexham's trees in 2013 were valued at more **£1.44 million** per year

- Wrexham has an urban tree density at **95 trees per hectare**, totalling **364 000 trees.** This is higher than the average in England
- Wrexham has **17% tree cover**, the **average** for Welsh towns
- The three most common tree species in Wrexham are **sycamore, hawthorn** and **silver birch**
- Wrexham has a high proportion of large trees compared to the rest of the UK
- Wrexham's urban forest would benefit from more medium and large sized trees to ensure large trees exist in the future
- The **replacement cost** (not including ecosystem services) of Wrexham's trees is around **£0.9 billion**
- The highest value trees for amenity in Wrexham are located in **cemeteries**
- Wrexham's urban forest intercepts **278 000 m^3 or water** every year, equivalent to an estimated **£460 000** in sewerage charges
- **60 tonnes of air pollution** are removed by Wrexham's trees per year, worth more than £700 000 in terms of the damage they cause
- **65 800 tonnes of carbon** are currently stored in Wrexham's trees
    - This is the equivalent of the **annual emissions of 109 000 cars**
    - This amount of carbon is estimated to be **worth £13.7 million**
    - **By 2050** this value will be **£25.9 million** according to current forecasts
- Each year Wrexham's trees **remove 1 300 tonnes of carbon** from the atmosphere
    - This **offsets 3%** of the emissions from **cars** owned in Wrexham
    - This amount of carbon is estimated to be **worth £278 000**
- **Willows, oaks and silver birch** support the highest diversity of herbivorous insects, including beetles, butterflies and moths

Introduction

Urban trees provide a range of ecosystem services, functions provided by nature on which human life depends or is significantly improved. Assessing the value of these services in Wrexham will enable Wrexham County Borough Council and other stakeholders to value the urban forest as an asset to the community, providing a baseline for future monitoring. In addition it will inform planting practises to maximise space and budgets and raise the profile of urban trees.

Urban forests provide a number of health benefits including improving local air and water quality by absorbing and filtering pollutants (Bolund and Hunhammar, 1999) and by reducing the urban heat island effect (Akbari *et al.,* 2001), decreasing illnesses associated with poor air quality and heat. There is also evidence that urban greenery can help reduce stress levels and improve recovery time from illness (Ulrich, 1979).

Simpson (2013)

Trees also provide a valuable habitat for much of the UK's urban wildlife, including bats (Entwistle *et al.,* 2001) and bees (RHS, 2012). They provide local residents with a focal point to improve social cohesion and aid education with regards to environmental issues (Trees for Cities, 2011).

Economic benefits are also provided by urban trees. Trees store carbon within their tissues and continually absorb carbon, helping to offset carbon emissions produced by other urban activities (Nowak *et al.,* 2008). In addition, urban trees help alleviate flash flooding, a problem that costs urban areas millions of pounds each year (Bolund and Hunhammar, 1999). Trees also increase property value, both commercially and privately (Forestry Commission, 2010).

A range of these benefits are quantifiable using models such as i-Tree Eco, developed by the US Forest Service to aid the sustainable management of urban trees, including planning tree planting. i-Tree Eco is currently the most complete method available to value a whole suite of urban forest ecosystem services (Sarajevs, 2011) and has been used successfully in over 60 cities globally, including studies in the UK. In this report we present the findings of the first such assessment in Wales. Wrexham and the surrounding towns and villages were surveyed, with data from trees and shrubs recorded to estimate the replacement costs of trees, their amenity value and the value of ecosystem services provided by Wrexham's urban forest.

Methodology

202 plots were selected from a randomised grid covering Wrexham and neighbouring towns and villages (Fig 1). This method was chosen to overcome problems associated with patchy land use, for example aggregations of industrial units in one area or residential properties in another. Grid squares present on the edges of the sample area were only included if they contained at least 50% of the grid square area. The total sample area was 3 833 Ha, resulting in a sample plot every 19 Ha. This provided a high density of plots, higher than previous studies in both Torbay (26 Ha) and Edinburgh (57 Ha).

i-Tree Eco uses a standardised field collection method outlined in the i-Tree Eco Manual (v 5.0 for this study) (USDA, 2013), and this was applied to each plot.

Each plot covered 0.04 Ha and from it was recorded:

- The type of land use it was, e.g. park, residential
- The percentage distribution of cover present in the plot e.g. grass, tarmac
- The percentage of the plot that could have trees planted in it[1]
- Information about trees (over 7 cm trunk girth)
    - The number of trees and their species
    - The size of the trees including height, canopy spread and girth of trunk
    - The health of the trees including the fullness of the canopy
    - The amount of light exposure the canopy receives
    - The amount of impermeable surface (e.g. tarmac) under the tree
- Information about shrubs (less than 7 cm in trunk girth, but over 1 m in height)
    - The number of shrubs and their species
    - The size and dimensions of the shrubs

Field operative Simon Morath measuring tree height (Simpson, 2013)

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

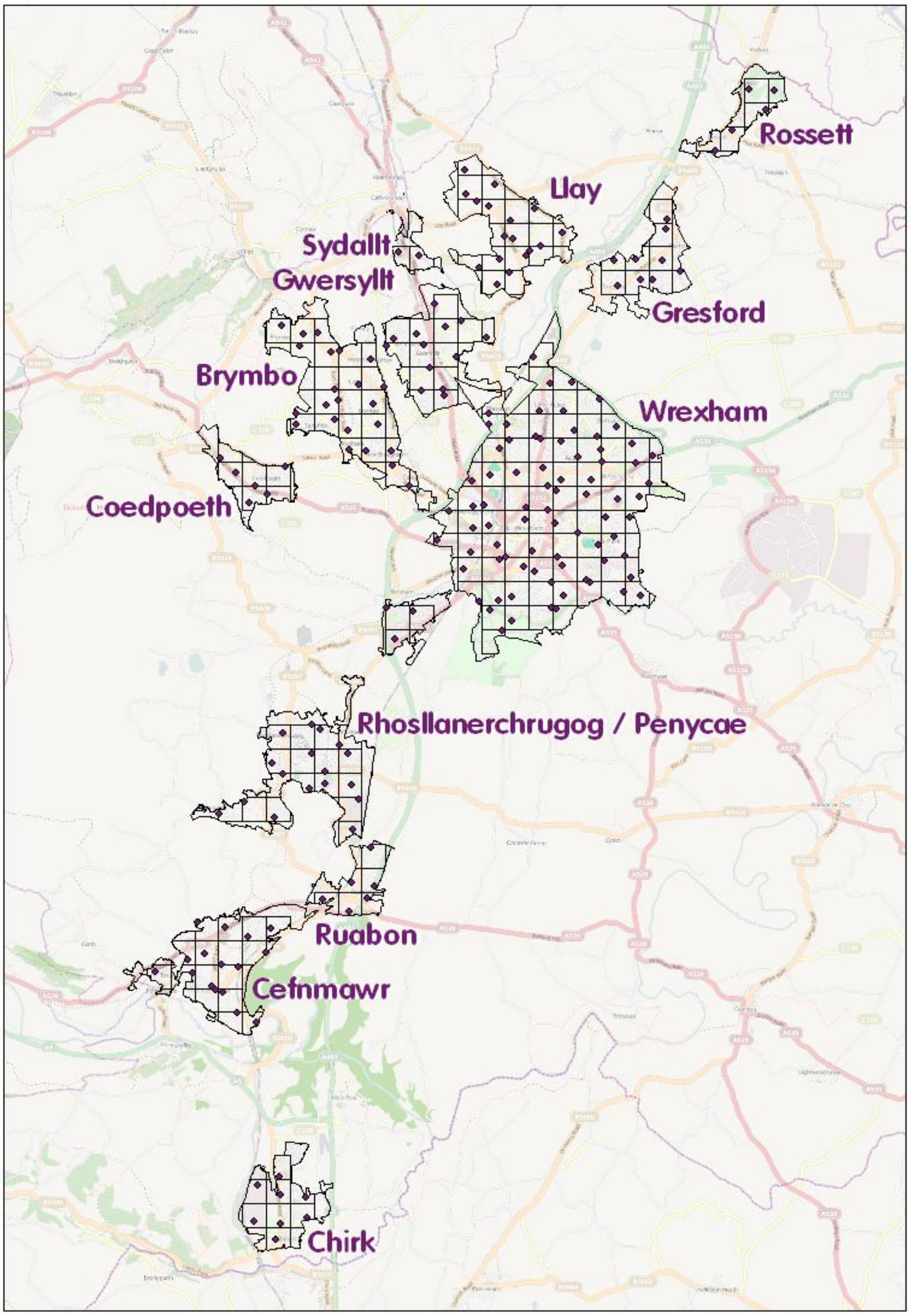


Fig 1. The sample area for the study included plots in Chirk, Cefn Mawr, Ruabon, Rhosllanerchrugog, Penycae, Wrexham, Coedpoeth, Brymbo, Gwersylt, Sydallt, Llay, Gresford and Rossett. In total 202 plots were sampled (basemap: ©OpenStreetMap contributors)

This information was submitted to the US Forest Service for use in the i-Tree Eco model and a number of outputs calculated (Table 1). i-Tree Eco calculates the species and age class structure, biomass and leaf area index (LAI) of the urban forest. This data is then combined with local climate and air pollution data to produce estimates of a number of ecosystem services (Table 1) and to assess their current and future value.

Weather data used was for the year 2012, recorded at Hawarden weather station, approximately 10 km North of the sample area (Met Office 2012). NO_2, SO_2, PM_{10} and $PM_{2.5}$ were recorded at the Victoria Road station, Wrexham, in 2012. O_3 (ozone) was recorded at the Mold station in 2012. CO was recorded at the Llay station in 2006. All pollution data was obtained from www.welshairquality.co.uk (2013).

Table 1. Outputs calculated based on field collected data

Urban forest structure and composition	Urban ground cover types Species diversity, canopy cover and age class % leaf area by species Phenology
Structural and functional values	Structural values in £ Carbon storage and sequestration value in £ Pollution removal value in £
Ecosystem services	Rainfall interception Air pollution removal by urban trees for CO, NO2, SO2, O3, PM10 and PM2.5 % of total air pollution removed by trees Current carbon storage by the urban forest Carbon sequestered
Habitat provision	Pollinating insects Insect herbivores
Potential insect and disease impacts	Acute oak decline, asian longhorn beetle, chalara dieback of ash, emerald ash borer, gypsy moth, oak processionary moth, *Phytophthora ramorum, Phytophthora kernoviae, Phytophthora lateralis,* red band needle blight, sweet chestnut blight

Mean average leaf-on/leaf-off dates were calculated using datasets from the UK phenology records (Natures Calendar, 2013). The data from 10 species were selected to calculate a UK average (field maple, sycamore, horse chestnut, common alder, silver birch, common beech, common ash, common oak, sessile oak and rowan) over a 5 year period (2009-2013) to provide a leaf-on date. However, because leaf-off is not in itself an event in the UK phenology database, a further average was taken from the first leaf fall and bare tree events for the 10 species across the five years (2008-2012) to provide an average date for the leaf off event.

Where outputs generated by i-Tree Eco were based on US values, UK government guidance was used to tailor values for a UK scenario. These included carbon (DECC, 2011) and pollution valuation (HM Treasury, 2011).

Additional structural values were also obtained. i-Tree Eco currently outputs tree values based on The Council of Tree and Landscape Appraisers (CTLA, 1992) valuation method. However, the Capital Asset for Amenity Trees (CAVAT) (Neilan, 2010) method was also used as this takes extra variables into account, such as tree health, appropriateness of the species to the site and the amenity value of the trees. Whereas CTLA values a tree in terms of the value to its owner, the additional amenity assessment in CAVAT adds a further social dimension, placing a public value on the tree. Both methods are widely used in the UK.

In addition to the outputs provided by i-Tree Eco, pest susceptibility was also assessed using information regarding the number of trees within pathogen/pest target groups. The habitat provided by different species was also assessed. A detailed methods section for both i-Tree Eco calculations and additional calculations is provided in Appendix I.

Simpson (2013)

Results and Discussion

Sample Area

Based on the plots sampled in Wrexham, approximately 28(±2)% of the ground cover could be planted with trees. Cover of trees was 17(±2)% of the sample area and shrubs covered 11(±1)% of the sample area. Tree cover in Wrexham is equal to the Welsh average but lower than neighbouring Llangollen (28%) and towns of a similar size such as Pontypool (24%) and Neath (23%).

52% of the ground cover in Wrexham consisted of permeable materials such as grass and soil (Fig 2). The remainder of the ground cover consisted of non-permeable surfaces such as tar and cement (Fig 2). Permeable surfaces alleviate problems associated with flash flooding, reducing loads on sewer systems. This can potentially prevent traffic incidents caused by flooding, as occurred in Wrexham in 2013 (wrexham.com, 2013) and sewer failures, also reported in Wrexham (heart.co.uk, n.d.). Wrexham has a lower percentage of permeable ground cover than Torbay (approx. 66%).

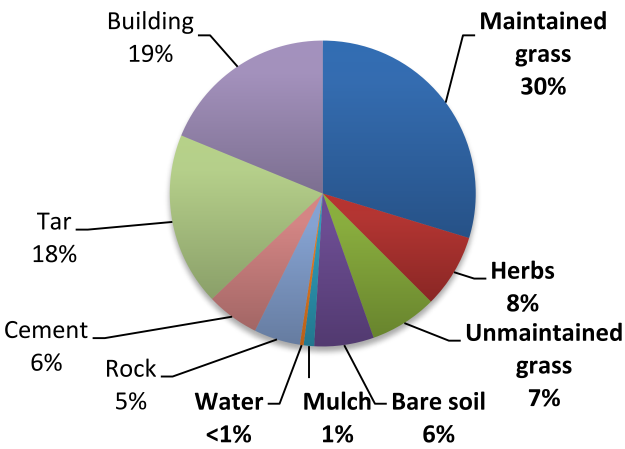


Fig 2. Types of ground cover encountered in Wrexham. Bold labels denote permeable surfaces, the remainder are non-permeable.

Urban Forest Structure

The urban forest of Wrexham and its neighbouring towns has an estimated population of 364 000 trees. This is a density of 95 trees per hectare, much higher than the UK average of 58 trees per hectare (Britt & Johnston, 2008). This density is higher than that found in Edinburgh (56 trees p/Ha) (Hutchings *et al.,* 2012), but lower than that found in

Torbay (105 trees[2] p/Ha) (Rogers *et al.*, 2011). Tree canopy cover is 17%, comparable to the Welsh average for towns of 16.8% and higher than the English average (8.2%) (Fryer, 2014).

The three most common species are sycamore (*Acer pseudoplatanus)*, hawthorn (*Crataegus monogyna)* and silver birch (*Betula pendula)* (Fig 3). The ten most common tree species account for 70% of the population (Fig 3).

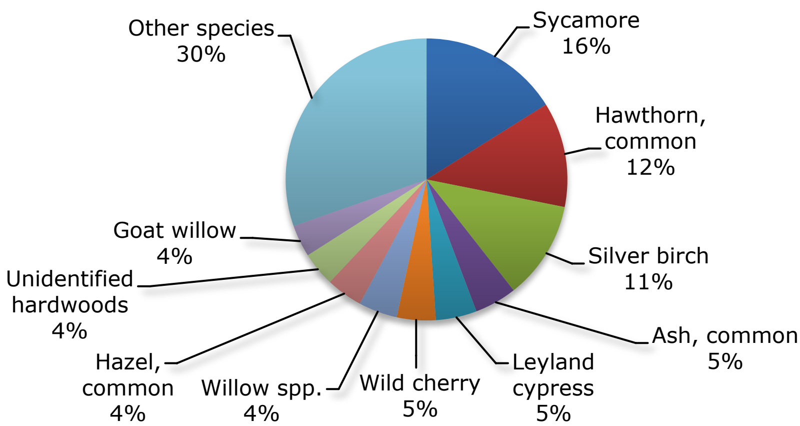


Fig 3. Breakdown of tree species in Wrexham and the surrounding towns.

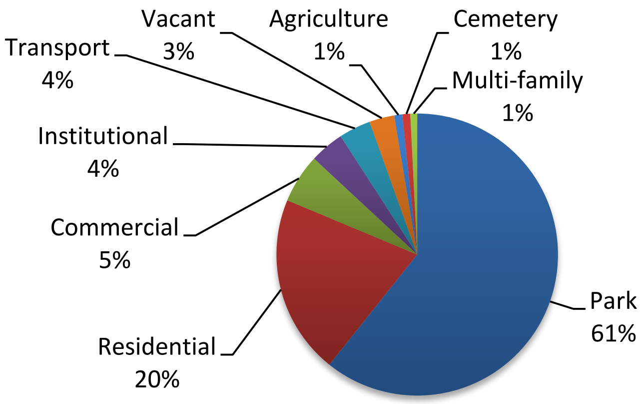


Fig 4. Proportion of trees on land use types where trees were found. Land use types where no trees were found are omitted.

[2] Torbay's Urban Forest (Rogers *et al.,* 2011) states a density of 128 trees p/Ha. However, trees smaller than those in the Wrexham and Edinburgh were measured. These have been filtered out and reanalysed for better comparison and it is these comparative values that are used throughout this report.

In plots where trees were found parks and residential areas contained the most trees (Fig 4).

The diversity of species can be calculated using the Shannon-Wiener index. This is a measure of not only the number of different species, but how whether the population is dominated by a certain species. The diversity of Wrexham's urban forest is 3.06 according to this index. This is marginally lower than was found in Torbay (3.3) (Rogers *et al.*, 2011) and Edinburgh (3.2). The highest diversity of trees was found in residential areas (Fig 5).

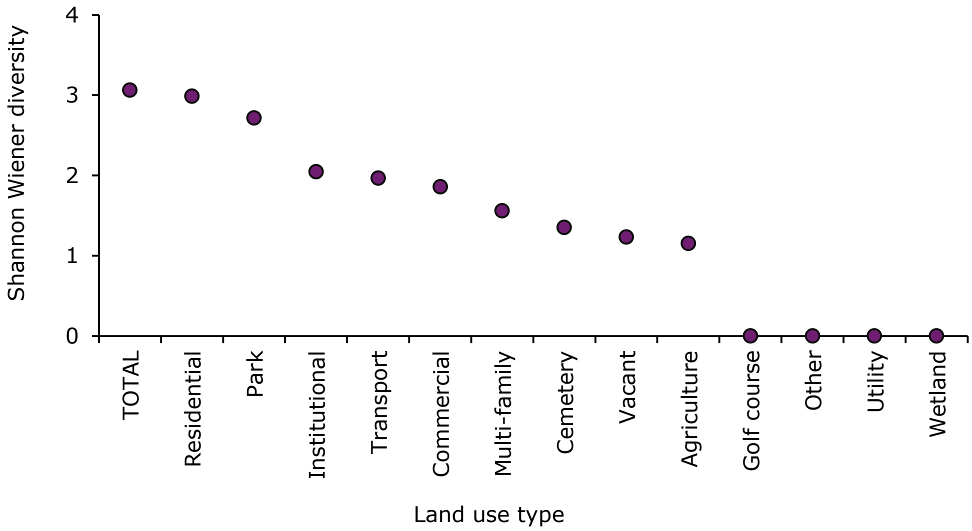


Fig 5. Shannon Wiener diversity for each study area on separate land use types.

Santamour (1990) recommends that for urban forests to be resilient to pests and diseases, no species should exceed 10% of the population, no genus 20% and no family 30%. Three species exceeded the 10% guideline (sycamore, hawthorn and silver birch; Fig 3). No genus exceeded 20% frequency and no family exceeded 30%.

In addition to diversity, where trees come from can be important. With new pests and diseases emerging, such as Chalara ash dieback, and with the onset of climate change some councils are considering the use of exotic species. Increasing the pool of trees available for tree officers to plant by including non-natives is also being considered to provide a wider range of options for successful tree survival. This is important in an urban area where there are additional challenges to tree planting, such as exposure to drought and insufficient rooting volumes. However, there is intense debate about whether the costs outweigh the benefits (Johnston *et al.,* 2011). Exotic species tend to have fewer pests associated with them due to being removed from the home range of their specialist herbivores and diseases (Connor *et al.,* 1980). However, they can also perturb native ecosystems by changing the available niches for wildlife to fill (Townsend *et al.,* 2008). They also support fewer native animals (Kennedy and Southwood, 1984) and can become invasive due to their lower association with pests (Mitchell and Power, 2003). Thus, a balance of native and non-native species may provide the most resilient solution.

In Wrexham, approximately 14% of the trees have origins in Europe. Most species (55.5%) have origins in both Europe and Asia (Fig 6). 59% of the trees in Wrexham are native to England and Wales, 22% are naturalised and 9% are non-native[3].

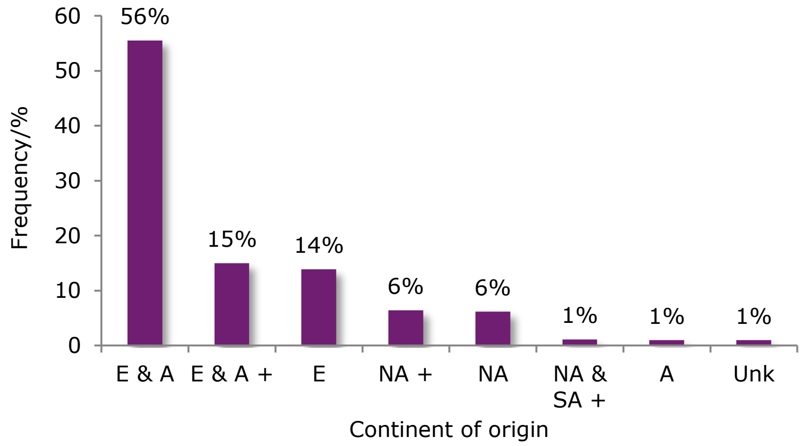


Fig 6. Origins of tree species in Wrexham. A:Asia; E:Europe; NA: North America; SA: South America; Unk: Unknown; + denotes origins from additional continents.

The size distribution of trees is also important. Large, mature trees offer unique ecological roles not offered by small, younger trees (Lindenmayer *et al.,* 2012), but young trees are needed to restock trees as they age and die. It is estimated that trees that have diameters (diameter at breast height; DBH) less than 15cm constitute 47% of the total tree population in Wrexham (Fig 7).

The number of trees in each DBH class declines successively, with only 28% of trees reaching DBH's of 20cm or above. This is at the higher end of the range of 20cm+ trees found in the majority of England (Britt and Johnston, 2008) but studies in North America suggest an ideal value of 60% for healthy urban tree stocks (Richards, 1983[4]). Large trees provide greater ecosystem services benefits (USDA, 2003) than small ones, so Wrexham County Borough could improve on this element.

[3] Some trees were identified to genus level only, encompassing both native and non-native species. Some trees were dead so could not be assessed for nativity. These two groups (dead trees and trees identified to genus level only) encompassed 10% of Wrexham's trees.
[4] Richards (1983) comments on the size classes of street trees necessary to maintain populations found in urban areas. However, street trees only made up a small proportion of the trees analysed in the current study and so there is a need for this work to be expanded further.

Using the DBH of trees to infer age, however, is a simplistic approach. In Wrexham County Borough, the large number of small trees is heavily influenced by the prevalence of hawthorn, a naturally small species even at maturity. Though there is evidence to suggest that large trees provide more ecosystem services than small growing ones (USDA, 2003), little work has been conducted to compare large growing trees with dense stands of comparable size such as those that hawthorn produce, so a value comparison in terms of the ecosystem services provided is difficult. Overall, a good strategy may be to supplement small growing trees with young, naturally larger growing trees in order to ensure large growing tree stocks are future proofed, without losing potentially valuable mature small growing tree stands.

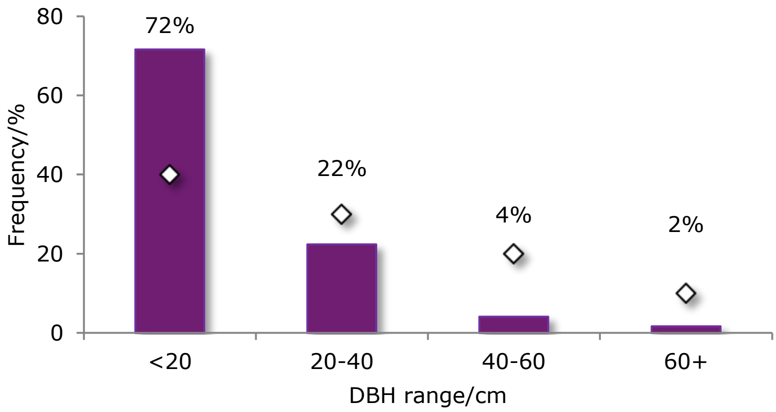


Fig 7. DBH ranges of trees encountered in Wrexham. Diamonds represent recommended frequencies for that dbh class as outlined in Richards (1983). Labels correspond to bars.

Large trees (60cm+) were found in higher proportions in cemeteries and multi-family residential areas (Fig 8).

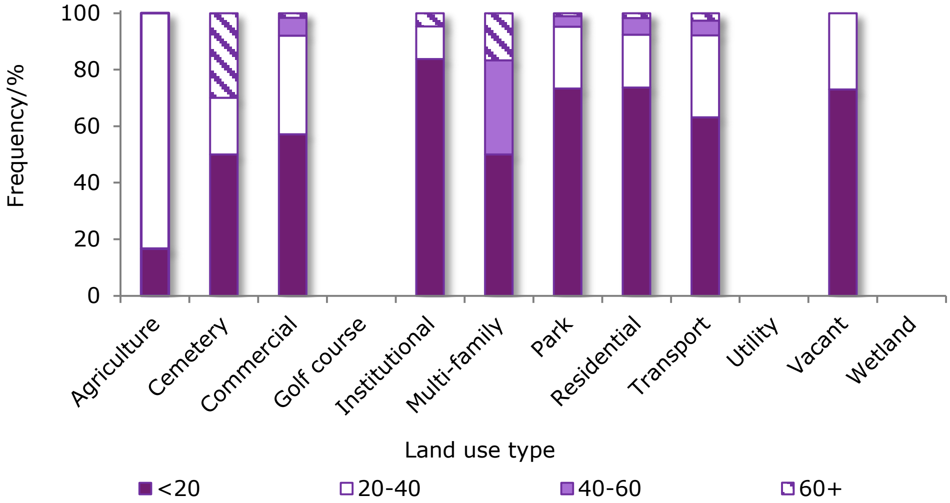


Fig 8. DBH ranges of trees encountered in Wrexham on different land use types

Tree condition was, on average, excellent with over 80% of trees achieving a Fair (11-25% dieback) to Excellent (no dieback) rating (Fig 9).

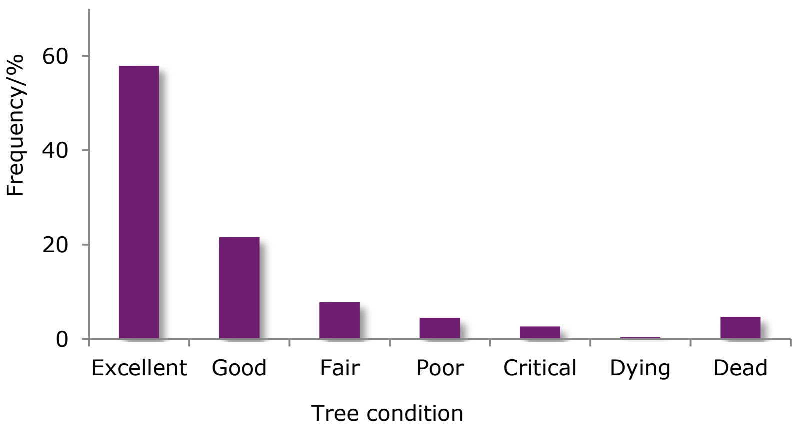


Fig 9. Condition of trees encountered in the Wrexham area.

Tree Cover and Leaf Area

Overall, tree cover in Wrexham was high, estimated at 17% across the region. This is higher than the English average of 8% (Britt & Johnston, 2008) and is average for Welsh urban areas (Fryer, 2014). Sycamore possessed the highest leaf area (Fig 10).

In addition to cover, the healthy leaf surface area of trees is a good indicator of the benefits they provide. The removal of pollutants from the atmosphere, for example, relies on leaf surface area (Nowak, 2006) and other factors such as shading are influenced by leaf area.

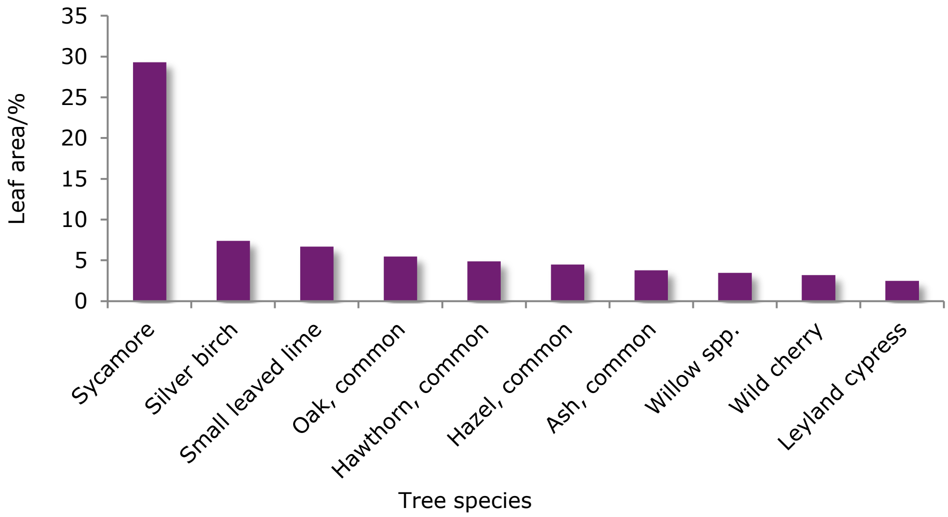


Fig 10. Tree species in order of leaf area/%.

Taking leaf area and prevalence into account, it is possible to rank tree species by calculating an "importance value" (IV).

In the case of the Wrexham study, all three of the most prevalent species are also leafy species (unlike if a softwood, such as Leyland Cypress, was prevalent) (Fig 11). This means that the three most prevalent species are also the three most important. Other species in the top 10 most important species, however, do not appear in the same order as prevalence (Fig 11).

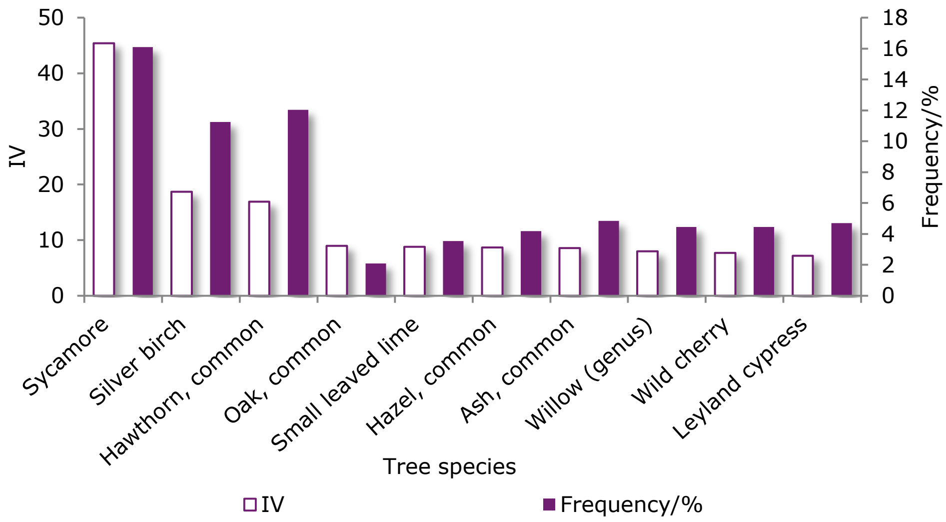


Fig 11. Importance value (IV) for the top ten most important trees and their frequency/%.

Phenology

Ecosystem service provision relies not only on the leaf area of trees but also the length of time each year that trees are in leaf. The date each year that trees come into leaf and later lose their leaves (i.e. phenology) varies depending on weather. The average date calculated for leaf on in the last five years was April the 14th. The average date calculated for leaf off in the last five years was November the 2nd. It was estimated, therefore, that trees in Wrexham were in leaf for approximately 202 days in 2013.

Structural value

Aside from the value associated with the ecosystem services provided by trees, trees also have a real cost, principally the cost of replacing them should they be lost or damaged. This can be helpful for tree owners should a tree be cut down unlawfully, for example if a person cuts a tree down that does not belong to them, or if a tree is damaged. A number of methods are used by arborists to value trees; here we present two of the most common in the UK and USA, CAVAT (Capital Asset Valuation for Amenity Trees) and CTLA (Council of Tree and Landscape Appraisers method).

CAVAT valuation

Wrexham's urban forest is estimated to be worth £1.4 billion according to CAVAT valuation, taking into account the health of trees and their amenity value. As an asset to the county borough, this is equivalent to nearly 350 times the cost of constructing the Mold Road football stand at Wrexham's Racecourse Ground. Black poplars in Wrexham County Borough hold the highest structural value (Fig 12), representing 26% of the value of all Wrexham County Borough's urban trees. The single most valuable tree encountered in the study was a black poplar situated in Wrexham Cemetery, estimated have an asset value of £793 000.

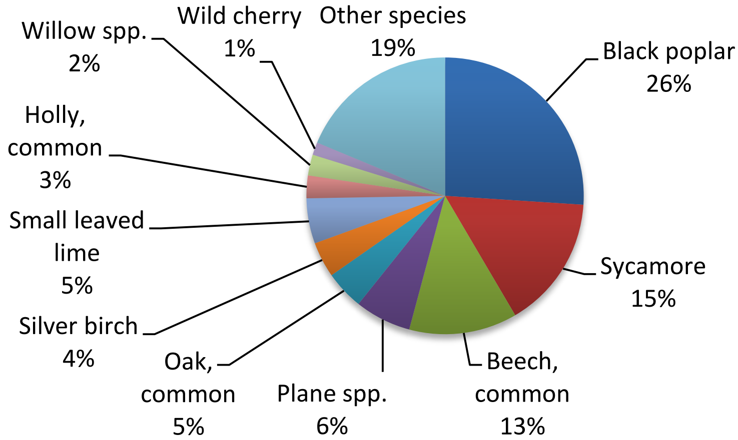


Fig 12. Percentage value held by tree species in Wrexham according to CAVAT analysis.

The land use type containing the highest structural value of trees is cemeteries, with the total value of trees within this land use type estimated at approximately £1.1 million in the plots sampled. This is 37% of the structural value held by Wrexham's trees (Fig 13) and is made even more notable by the fact that only one cemetery plot was sampled (Table 2).

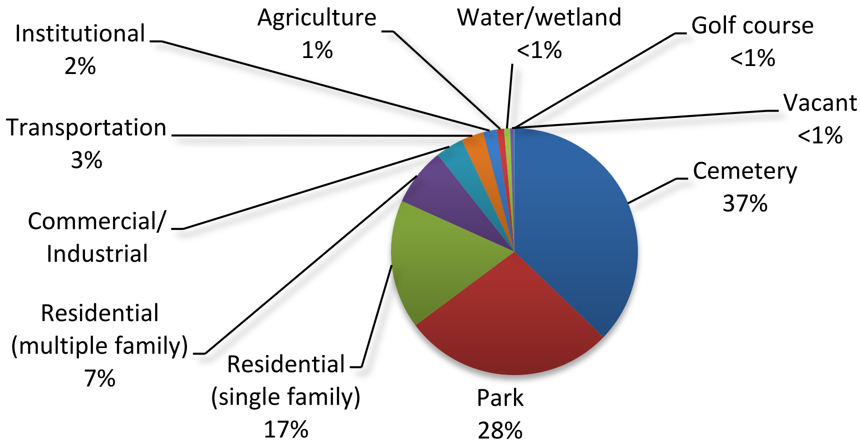


Fig 13. Percentage of structural value held by trees on different land use types according to CAVAT analysis. Land use types where no trees were found are omitted.

Table 2. Structural value of trees encountered in different land use types in plots and the number of plots containing each land use type

Land use type	Structural value (in plots)/£	Value/%	No. of plots§
Cemetery	1 117 986	37.2	1
Park	829 857	27.6	58
Residential (single family)	508 608	16.9	93
Residential (multiple family)	228 359	7.6	10
Commercial/Industrial	110 070	3.7	28
Institutional	53 318	1.8	15
Agriculture	28 756	1.0	7
Water/wetland	24 111	0.8	1
Vacant	14 581	0.5	7
Other	2 321	0.1	1
Golf course	0	0.0	1

§ Number of plots containing this land use type

CTLA Valuation

According to CTLA valuation, which does not take into account the health or amenity value of trees, Wrexham's urban forest is worth approximately £0.9 billion. This is the cost of replacing Wrexham's urban forest should it be lost.

Avoided Surface Water Runoff

The infrastructure required to remove surface water from towns and cities is costly and in some areas of the UK can be overwhelmed by large storm events, where surface water may not be removed quickly enough. This can result in flooding and damage. Trees can intercept rainwater, retaining it on their leaves and absorbing some into their tissues for use in respiration. The trees in Wrexham intercept approximately 278 000 m^3 of water per year, the equivalent of Wrexham Waterworld's main pool being filled 556 times. Based on the standard local rate charged for sewerage[5], this would save £460 000 in sewerage charges.

Sycamore intercepts the most water, removing 81 000 m^3 of water per year, worth £135 000 in sewerage charges (Fig 14).

[5] This value is based on the 2013 household standard volumetric rate per cubic metre charged by Dwr Cymru and does not include standing charges or special discounts. This rate is stated as £1.6554 per m^3 (Dŵr Cymru, 2013)

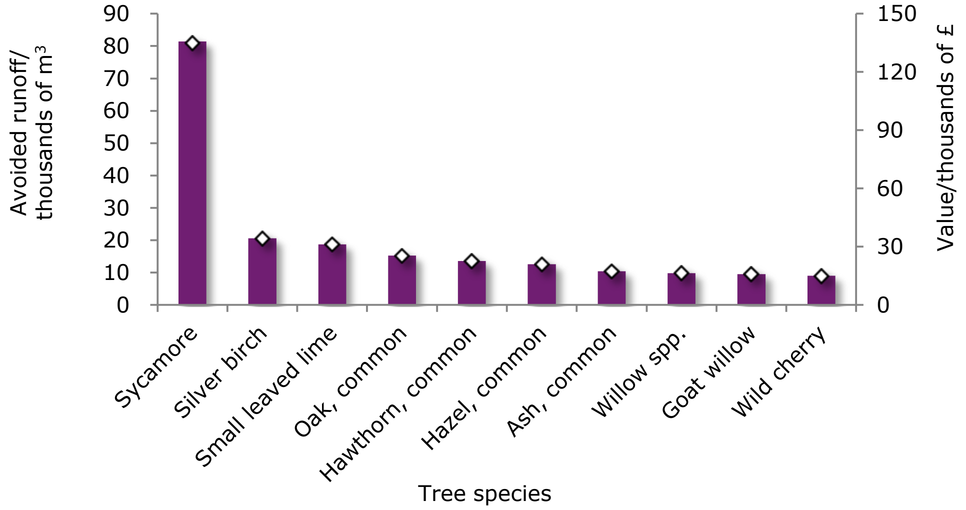


Fig 14. Avoided surface water runoff provided by urban trees in Wrexham (columns) and their associated value in avoided sewer costs (diamonds)

Air Pollution Removal

Air pollution is harmful to human health and can lead to a decrease in the quality of ecosystems (Table 3). The centre of Wrexham has some of the highest deaths caused by respiratory problems in Wales, with 111 respiratory related deaths for every 100 000[6] people (www.healthmapswales.wales.nhs.uk, 2010). This puts Wrexham in the top 20% of Welsh areas for respiratory related deaths. However, respiratory diseases can be caused by a number of factors in addition to air pollution, including smoking.

[6] Standardised by age

Table 3. Urban pollutants, their health effects and causes (air-quality.org.uk)

Pollutant	Health effects	Source
NO_2	Shortness of breath Chest pains	Fossil fuel combustion, predominantly power stations (21%) and cars (44%)
O_3	Irritation to respiratory tract, particularly for asthma sufferers	From NO_2 reacting with sunlight
SO_2	Impairs lung function Forms acid rain that acidifies freshwater and damages vegetation	Fossil fuel combustion, predominantly burning coal (50%)
CO	Long term exposure is life threatening due to its affinity with haemoglobin	Carbon combustion under low oxygen conditions i.e. in petrol cars
PM_{10} and $PM_{2.5}$	Carcinogenic Responsible for 10 000 premature deaths per year	Varied causes, cars (20%) and residential properties (20%) major contributors

Trees and shrubs can mitigate the impacts of air pollution by directly reducing airborne pollutants as well as reducing local temperatures. Trees may absorb pollutants through their stomata, or simply intercept pollutants that are retained on the plant surface (Nowak *et al*., 2006). This leads to year-long benefits, with bark continuing to intercept pollutants throughout winter (Nowak *et al*., 2006). Plants also reduce local temperatures by providing shade and by transpiring (Bolund and Hunhammar, 1999), reducing the rate at which air pollutants are formed, particularly ozone (i.e. O_3) (Jacob and Winner, 2009). However, trees can also contribute to ozone production by emitting volatile organic compounds (VOC's) that react with pollutants (Lee *et al.,* 2006). Research indicates that, of the trees present in Wrexham, common oak, goat willow, poplar and sessile oak have the potential to worsen air quality through release of VOC's (Stewart *et al.,* (2002). i-Tree takes the release of VOC's by trees into account to calculate the net difference in ozone production and removal.

It is estimated that 60 tonnes of airborne pollutants per year are removed by Wrexham's urban forest, including NO_2, ozone, SO_2, CO and PM_{10} and $PM_{2.5}$. Ozone showed the greatest reduction by urban trees, demonstrating that although trees can increase ozone levels by producing VOC's, they remove far more than they produce. In addition, as ozone is produced by trees only in warm temperatures, the cooling benefits of trees reduce ozone production overall (Nowak *et al.,* 2000).

The pollution removed from the atmosphere can be valued to aid interpretation of this data. In both the USA and the UK, pollutants are valued in terms of the damage they cause to society. However, these are valued by slightly different methods in each country, using United States Externality Costs in the US (USEC) and United Kingdom Social Damage Costs (UKSDC) in the UK. The UK method does not cover all airborne pollutants (Table 4).

Using the US valuation system, £637 500 worth of pollutants are removed by urban trees in Wrexham (Fig 15). Using the UK system, which only accounts for three pollutants, £669 500 worth of pollutants and removed from the atmosphere (Table 4).

Table 4. Amount of each pollutant removed by the urban forest and its associated value. Dashes denote unavailable values. USEC denotes United States Externality Cost, UKSDC denotes United Kingdom Social Damage Cost

Pollutant	Mean amount removed/tonnes per annum	US value per tonne/£	USEC value/£	UK value per tonne/£	UKSDC value/£
CO	1.51	1714	2585	-	-
NO_2	8.45	12066	101 984	955 (NO_x)	8072
O_3	33.97	12066	410 072	-	-
PM_{10}	11.91	8056	95 877	55 310 (PM)	658 300
$PM_{2.5}$	2.66	8056	21 443	55 310 (PM)	-
SO_2	1.87	2954	5 531	1633 (SO_x)	3059

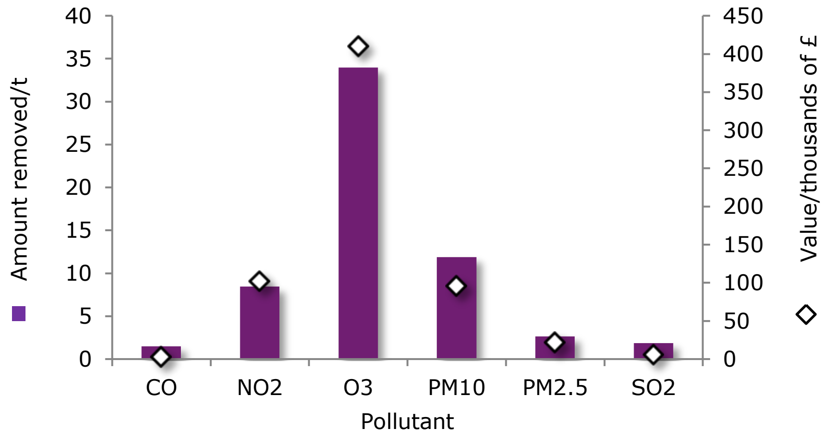


Fig 15. Mean pollutants removed by urban trees in Wrexham (columns) and their associated value (diamonds) as valued using the USA externality system. PM_{10} excludes particles smaller than 2.5 microns.

The volume of airborne pollutants varied over the year, with a seasonal pattern evident in the removal of ozone, which was removed in higher volumes during the summer (Fig 16). This is because ozone, a product of the combination of NO_x and VOC's, is more prevalent in warm temperatures (Sillman and Samson, 1995). This also creates a diurnal pattern, with ozone levels higher during the day than at night (Nowak, 2000). $PM_{2.5}$ removal peaked in January due to high concentrations of the pollutant and thus more pollutant to accumulate on the trees and low wind speeds, reducing the amount of pollutant suspended into the air.

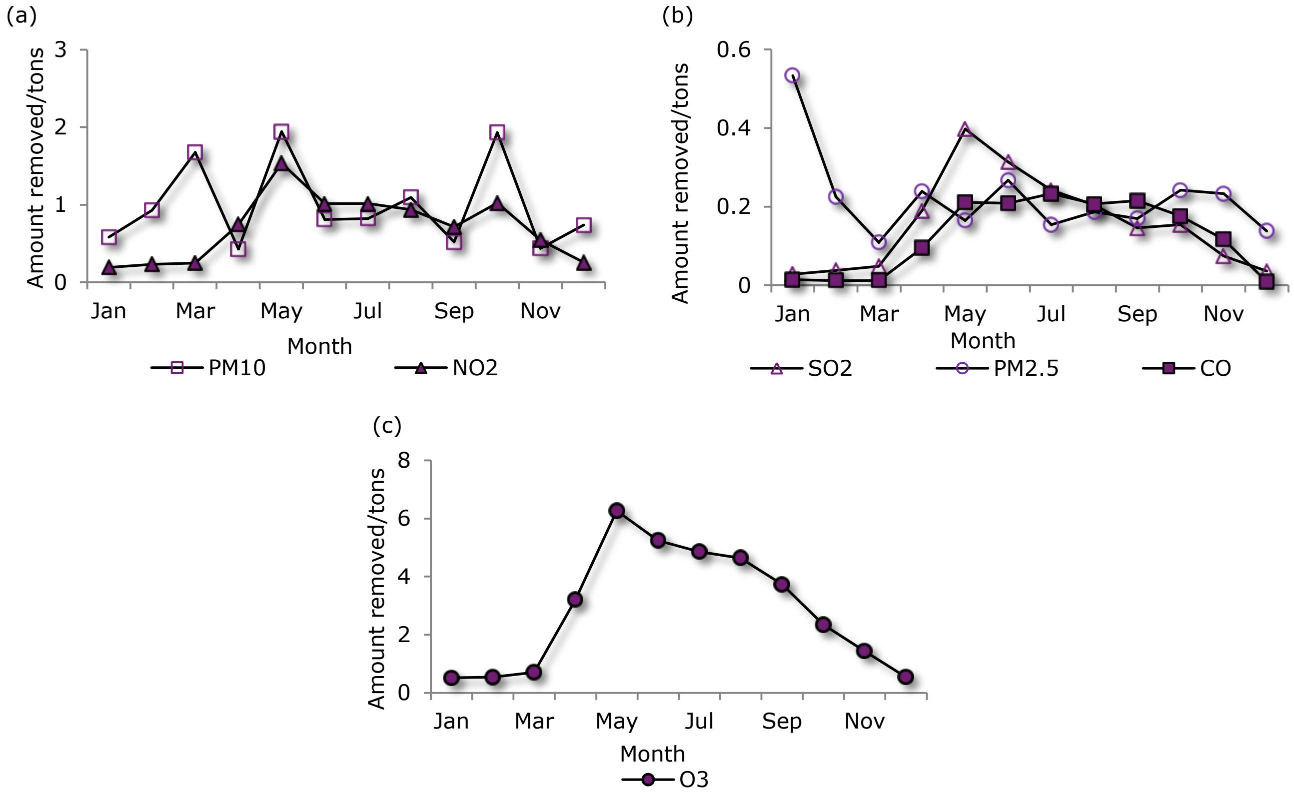


Fig. 16. Monthly pollutants removed by Wrexham's urban trees. (a) PM_{10}'s and NO_2, (b) SO_2, $PM_{2.5}$'s and CO and (c) O_3

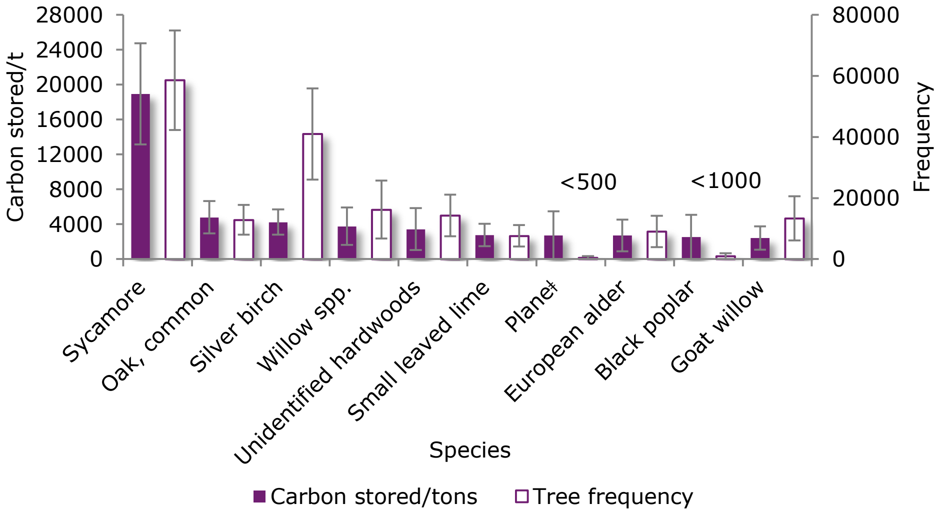
Carbon Storage and Sequestration

Wrexham's trees store a total of 65 773 tonnes of carbon in their wood, with sycamore storing the greatest amount (Fig 17). This is equivalent to the annual carbon emissions of 48 234 homes[7] and equates to 85% of the carbon emissions produced by Wrexham County Borough households[8]. Alternatively, this is the equivalent of the annual CO_2 emissions of 109 015 cars[9], more than (162%) the annual emissions of all cars estimated to be owned in the county borough[10].

Similarly to leaf area, carbon storage depends not only on the number of trees present, but also their characteristics. In this case, the mass of a tree is extremely important, as larger trees store more carbon in their tissues. Common oak (*Quercus robur*), for

[7] Based on an average UK household emission of 5 tonnes of CO_2 per year in 2009 (Palmer and Cooper, 2011)
[8] Conservative estimate based on the number of households recorded in the 2011 census for the entire county borough (ONS, 2011)
[9] Based on average emissions of 163g/CO_2 per km (DVLA 2013), with the average UK car travelling 13 572km per year (DVLA, 2010)
[10] Based on the average UK car ownership figure of 0.5 cars per person (DVLA, 2013), multiplied by the population of Wrexham County Borough (ONS, 2011)

example, only makes up 3.5% of Wrexham's tree population, but it is responsible for storing 7.3% of the total carbon stored in trees, the second largest contribution by a single species.



‡London Plane or Oriental Plane

Fig 17. Amount of carbon stored in Wrexham's urban forest and the frequency of each species in Wrexham. Only the ten trees with the highest storage rates are displayed.

Two species, plane (*Platanus x acerifolia* or *Platanus orientalis*) and black poplar (*Populus nigra*), also stored a high mass of carbon compared to their frequency in the population, storing 4% each of the total carbon stored whilst only representing 0.1 and 0.3% of the tree population respectively. This is an example of where extremely large trees may have biased the sample as in both cases one or two exceptionally large individuals were encountered[11]. Common oak has a lower standard error than these two species, suggesting that this species was encountered more frequently and was consistently large.

The gross amount of carbon sequestered by the urban forest in Wrexham each year is 2 376 tonnes. Taking into account the number of dead trees (net storage), which release carbon back into the atmosphere when they decay, Wrexham's urban forest sequesters 1 329 tonnes of carbon per year (350 kg/Ha). This is the equivalent to the annual emissions from 2 203 vehicles (or the emissions from 3% of the number of cars estimated to be owned in Wrexham County Borough), or 975 family homes (2% of Wrexham's total estimated households).

[11] Two black poplars were encountered in the study with dbh's of 100cm and 94cm. One oriental plane was encountered with a dbh of 155cm.

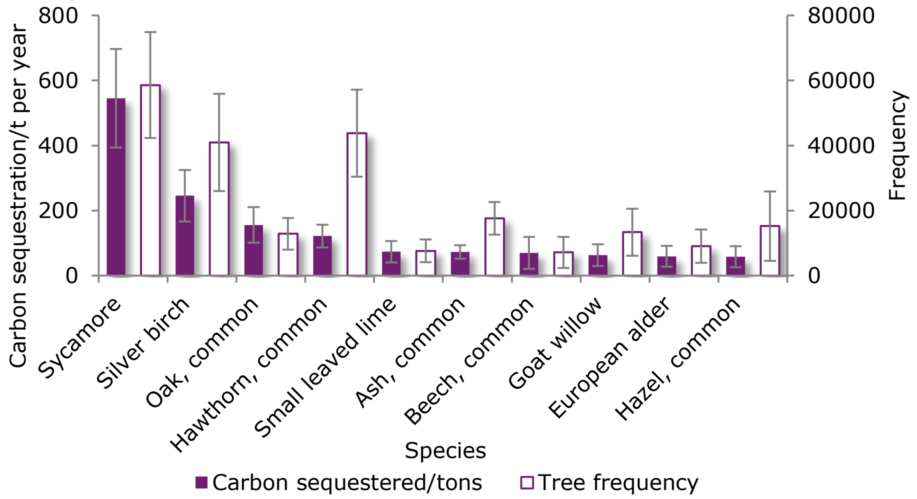


Fig 18. Carbon sequestered per year by the ten trees with highest rates, along with their frequency. Error bars denote standard error of the mean (SEM).

Plane and common oak were the only identified trees to be losing carbon on an annual basis, losing 1.2 and 1.3 tonnes per year respectively. This signifies that these populations are dominated by ageing trees that emit more carbon than they sequester. Aside from these species, dead trees produce around 590 tonnes of carbon per year in Wrexham. However, it must be noted that deadwood provides valuable habitat for a variety of species, some with economic importance, as do the large trees that are losing carbon, such as oak and plane (Hagan and Grove, 1999; Kennedy and Southwood, 1984). It is, therefore, important to retain this component of the urban forest.

The carbon stored and sequestered by trees can be valued within the framework of the UK government's carbon valuation method (HM Treasury, 2011). This is based on the cost of fines imposed if the UK does not meet carbon reduction targets and is split into two sets of values, traded and non-traded. Traded values are for industries covered by the European Union Emissions Trading Scheme. Tree stocks do not fall within this category so non-traded values have been used. There are also three sets of carbon value, low, central and high, that reflect the fact that carbon value could change due to outer circumstances, such as fuel price.

Based on the central scenario for non-traded carbon, it is estimated that the current tree stock is storing carbon worth 13.7 million; by 2050, this carbon is estimated to be worth £25.9 million, assuming that the structure of the forest in terms of species assemblage, tree size and population size remains unchanged (Fig 19). Table 5 outlines values from now until 2050 for all three value scenarios, again assuming no changes to Wrexham's urban forest occur in this time.

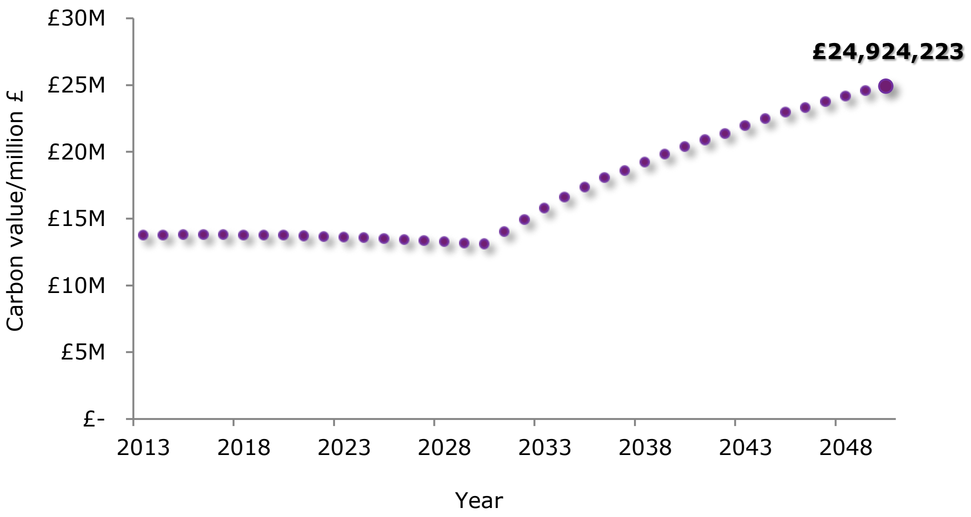


Fig 19. Value of stored carbon within Wrexham's urban forest during the period 2013-2050. These values are based on the UK governments non-traded carbon valuation method and assume the structure of the urban forest remains the same over time.

Table 5. Non-traded values for the carbon stored in Wrexham's trees in all three valuation scenarios. These values are based on the UK governments non-traded carbon valuation method and assume the structure of the urban forest remains the same over time

					Non-traded unit value (£/tCO2e)				Value of discounted stored tCO2e		
Year	Stored C (t)	Net sequestered C (t)	Stored C (tCO2e)	Net sequestered C (tCO2e)	Low	Central	High	Discount rate	Low	Central	High
2013	65,773	1,329	241,168	4,873	29	57	86	3.5	£6,993,862	£13,746,557	£20,740,419
2014	67,102	1,329	246,041	4,873	29	58	87	3.5	£6,893,893	£13,787,786	£20,681,679
2015	68,431	1,329	250,914	4,873	30	59	89	3.5	£7,026,918	£13,819,605	£20,846,523
2016	69,760	1,329	255,787	4,873	30	60	90	3.5	£6,921,148	£13,842,295	£20,763,443
2017	71,089	1,329	260,660	4,873	30	61	91	3.5	£6,814,495	£13,856,140	£20,670,635
2018	72,418	1,329	265,533	4,873	31	62	93	3.5	£6,930,713	£13,861,426	£20,792,138
2019	73,747	1,329	270,406	4,873	31	63	94	3.5	£6,819,231	£13,858,437	£20,677,667
2020	75,076	1,329	275,279	4,873	32	64	95	3.5	£6,923,729	£13,847,459	£20,554,822
2021	76,405	1,329	280,152	4,873	32	65	97	3.5	£6,808,013	£13,828,777	£20,636,790
2022	77,734	1,329	285,025	4,873	33	66	99	3.5	£6,901,337	£13,802,674	£20,704,011
2023	79,063	1,329	289,898	4,873	33	67	100	3.5	£6,781,959	£13,769,432	£20,551,391
2024	80,392	1,329	294,771	4,873	34	68	102	3.5	£6,864,665	£13,729,330	£20,593,994
2025	81,721	1,329	299,644	4,873	34	69	103	3.5	£6,742,172	£13,682,643	£20,424,815
2026	83,050	1,329	304,517	4,873	35	70	105	3.5	£6,814,823	£13,629,645	£20,444,468
2027	84,379	1,329	309,390	4,873	36	71	107	3.5	£6,880,871	£13,570,606	£20,451,477
2028	85,708	1,329	314,263	4,873	36	72	108	3.5	£6,752,896	£13,505,792	£20,258,687
2029	87,037	1,329	319,136	4,873	37	73	110	3.5	£6,809,755	£13,435,462	£20,245,217
2030	88,366	1,329	324,009	4,873	37	74	111	3.5	£6,679,938	£13,359,875	£20,039,813
2031	89,695	1,329	328,882	4,873	41	81	122	3.5	£7,259,341	£14,341,626	£21,600,967
2032	91,024	1,329	333,755	4,873	44	88	132	3.5	£,638,593	£15,277,186	£22,915,779

					Non-traded unit value (£/tCO2e)				Value of discounted stored tCO2e		
Year	Stored C (t)	Net sequestered C (t)	Stored C (tCO2e)	Net sequestered C (tCO2e)	Low	Central	High	Discount rate	Low	Central	High
2033	92,353	1,329	338,628	4,873	47	95	142	3.5	£7,998,588	£16,167,358	£24,165,945
2034	93,682	1,329	343,501	4,873	51	102	153	3.5	£8,506,490	£17,012,981	£25,519,471
2035	95,011	1,329	348,374	4,873	54	109	163	3.5	£8,825,745	£17,814,930	£26,640,675
2036	96,340	1,329	353,247	4,873	58	116	173	3.5	£9,287,055	£18,574,110	£27,701,044
2037	97,669	1,329	358,120	4,873	61	122	184	3.5	£9,567,305	£19,134,610	£28,858,756
2038	98,998	1,329	362,993	4,873	65	129	194	3.5	£9,983,952	£19,814,304	£29,798,255
2039	100,327	1,329	367,866	4,873	68	136	204	3.5	£10,227,019	£20,454,039	£30,681,058
2040	101,656	1,329	372,739	4,873	72	143	215	3.5	£10,601,016	£21,054,796	£31,655,812
2041	102,985	1,329	377,612	4,873	75	150	225	3.5	£0,808,785	£21,617,570	£32,426,355
2042	104,314	1,329	382,485	4,873	78	157	235	3.5	£11,001,160	£22,143,361	£33,144,521
2043	105,643	1,329	387,358	4,873	82	164	246	3	£11,316,588	£22,633,177	£33,949,765
2044	106,972	1,329	392,231	4,873	85	171	256	3	£11,532,216	£23,200,104	£34,732,320
2045	108,301	1,329	397,104	4,873	89	178	266	3	£11,868,859	£23,737,717	£35,473,218
2046	109,630	1,329	401,977	4,873	92	184	277	3	£12,057,756	£24,115,513	£36,304,332
2047	110,959	1,329	406,850	4,873	96	191	287	3	£12,363,624	£24,598,461	£36,962,086
2048	112,288	1,329	411,723	4,873	99	198	297	3	£12,526,893	£25,053,785	£37,580,678
2049	113,617	1,329	416,596	4,873	103	205	308	3	£12,803,188	£25,482,074	£38,285,262
2050	114,946	1,329	421,469	4,873	106	212	318	3	£12,941,961	£25,883,922	£38,825,883

Habitat Provision

Trees and shrubs provide valuable habitat and food for many animal and plant species, from non-vascular plants, such as moss, to insects, birds and mammals. Two examples are included in this section to highlight some of the organisms trees can support. For a broader review see Alexander, Butler and Green (2006).

Pollinating insects provide ecosystem services by pollinating food crops, but they are under threat from a number of pressures including land-use intensification and climate change (Vanbergen and the Insect Pollinators Initiative, 2013). Providing food sources could alleviate this. Twenty nine of the tree and shrub genus's found in Wrexham support pollinating insects (RHS, 2012) (Table 6).

Table 6. Species/genus encountered in Wrexham that are beneficial to pollinators (RHS, 2012)

Tree/shrub	Genus/ Species	Season	Tree/shrub	Genus/ Species	Season
Acer	Genus	Spring	*Malus*	Genus	Spring
Acer campestre	Species	Spring	*Malus domestica*	Species	Spring
Acer platanoides	Species	Spring	*Pieris*	Genus	Spring
Acer pseudoplatanus	Species	Spring	*Prunus*	Genus	Spring
Berberis	Genus	Spring	*Prunus avium*	Species	Spring
Berberis darwinii	Species	Spring	*Prunus domestica*	Species	Spring
Berberis thunbergii	Species	Spring	*Prunus laurocerasus*	Species	Spring
Buddleja davidii	Species	Summer	*Prunus spinosa*	Species	Spring
Buxus	Genus	Spring	*Pyracantha*	Genus	Summer
Buxus sempervirens	Species	Spring	*Pyrus*	Genus	Spring
Calluna vulgaris	Species	Summer	*Ribes*	Genus	Spring
Cornus	Genus	Spring, Summer	*Rosa*	Genus	Summer
Cotoneaster	Genus	Spring, Summer	*Rosa canina*	Species	Summer
Cotoneaster horizontalis	Species	Summer	*Rubus*	Genus	Summer
Crataegus monogyna	Species	Spring, Summer	*Rubus fruticosus*	Species	Summer
Fatsia japonica	Species	Autumn	*Salix*	Genus	Spring
Hebe	Genus	Spring, Summer	*Salix caprea*	Species	Spring
Hydrangea	Genus	Summer	*Sorbus*	Genus	Summer
Ilex	Genus	Spring, Summer	*Sorbus aucuparia*	Species	Summer
Ilex aquifolium	Species	Spring, Summer	*Tilia*	Genus	Summer
Laurus	Genus	Summer	*Tilia cordata*	Species	Summer
Ligustrum	Genus	Summer	*Tilia platyphyllos*	Species	Summer
Ligustrum sinense	Species	Summer	*Viburnum*	Genus	Winter
Lonicera	Genus	Winter	*Weigela*	Genus	Summer
Mahonia spp.	Genus	Winter, Spring			

Insect herbivores are another large group supported by trees. Some specialise on one or two species of tree, whilst other are generalists that benefit from multiple tree and shrub species. Of the species found in Wrexham, native oaks and willows support the highest number of different species (Fig 20). Beetles, however, are best supported by a single species, Scots pine (Table 7), highlighting that though some species have fewer insects associated with them, they are extremely important for certain groups.

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

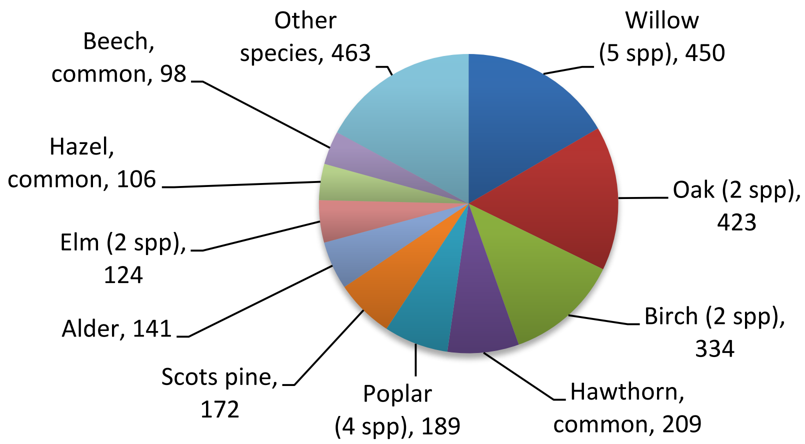


Fig 20. The number of insect species that associate with trees found in the Wrexham survey[12]. Where multiple species are denoted in brackets, insect species associate with more than one host (e.g. Common oak and sessile oak support the same insect species or the literature does not separate these two species). Data from Kennedy and Southwood (1984).

[12] NB: Insect data is not available for all species encountered in Wrexham; only species studied in Kennedy and Southwood (1984) are included. Some closely related species such as apples and pears have not been included because data was not available for the domesticated species.

Table 7. Species of insect supported by trees encountered in Wrexham, sorted by total number. Bold species names denote non-native species. Brightest green boxes denote the highest number of species supported in that insect group, red the lowest and middle values are represented by a gradient between the two ("Total" column shows gradient in order). Data from Southwood (1961) and Kennedy and Southwood (1984)

Species	Total	Beetles	Flies	True bugs	Wasps/ sawflys	Moths/ butterflies	Other
Willow (5 spp)	450	64	34	56	104	162	9
Oak (2 spp)	423	67	7	43	70	189	9
Birch (2 spp)	334	57	5	30	42	179	9
Hawthorn	209	20	5	23	12	124	8
Poplar (4 spp)	189	32	14	34	29	69	3
Scots pine	172	87	2	10	11	41	6
Alder	141	16	3	18	21	60	9
Elm (2 spp)	124	15	4	22	6	55	11
Hazel	106	18	7	3	8	48	6
Beech	98	34	6	7	2	41	4
Norway spruce	70	11	3	14	10	22	1
Ash	68	1	9	7	7	25	9
Rowan	58	8	3	6	6	33	2
Lime (2 spp)	57	3	5	7	2	25	8
Hornbeam	51	5	3	10	2	28	2
Field maple	51	2	5	10	2	24	6
Sycamore	43	2	3	10	2	20	5
Larch	38	6	1	6	5	16	1
Sweet chestnut	11	1	0	1	0	9	0
Holly	10	4	1	2	0	3	0
Yew	6	0	1	1	0	3	1

Risks of Pests and Disease

Pests and diseases are a serious threat to urban forests. Severe outbreaks have occurred within living memory, with Dutch Elm Disease killing approximately 30 million trees in the UK (Webber, 2010). In addition, climate change may make some pest and disease outbreaks more likely (Forestry Commission, 2014a). Assessing the risk pests and diseases pose to urban forests is, therefore, of paramount importance.

Acute Oak Decline

Acute oak decline (AOD) affects mature trees (>50 years old) of both the native oak species (*Quercus robur*, known as common oak and *Quercus petraea* - sessile oak). Over the past three to four years there have been a growing number of reports of oak trees with symptoms of stem bleeding, a potential sign of AOD. The incidence of AOD in Britain is unquantified at this stage but estimates put the figure at a few thousand affected trees. The condition appears to be most prevalent in the Midlands and the South East. Acute Oak Decline poses a threat to 5.9% of Wrexham's urban forest.

Asian Longhorn Beetle

Asian Longhorn Beetle (ALB) is a major pest in China, Japan and Korea where it kills many species of broadleaved trees. In America, ALB has established populations in Chicago and New York where the damage to street trees is high with felling, sanitation and quarantine are the only viable management options. We can expect extensive damage to urban trees if the ALB establishes in the UK.

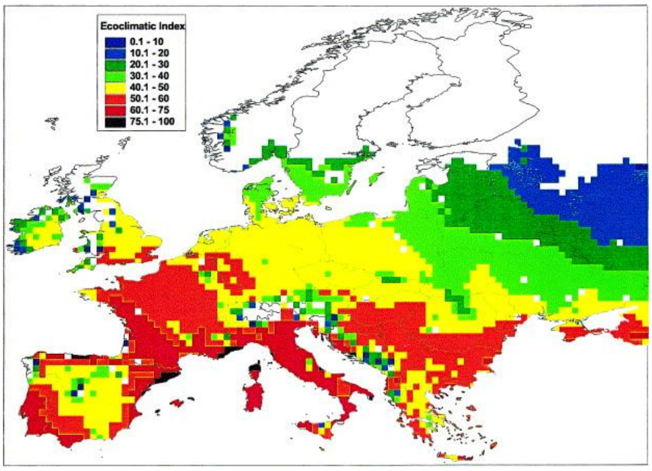


Fig 21. MacLeod *et al.,* (2002). Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB.

In March 2012 an ALB outbreak was found in Maidstone, Kent. The Forestry Commission and Fera removed 2 166 trees from the area to contain this outbreak and no further outbreaks have been reported in the UK. MacLeod *et al.,* (2002) modelled climatic suitability for outbreaks based on outbreak data from China and the USA and suggested that CLIMEX (the model used) Ecoclimatic Indices of >32 could be suitable habitats for ALB. This research suggests that Wrexham County may not be suitable for ALB (Fig 21). Recent reports by the Forestry Commission (2014b) suggest that the climate in Wales may be suitable for ALB, but that the major threat in the UK is to South-East England and the South coast.

If an ALB outbreak occurred in Wrexham it would pose a significant threat to 41.1% of Wrexham’s trees.

The known host tree and shrub species include:

- *Acer spp.* (maples and sycamores)
- *Aesculus spp.* (horse chestnut)
- *Albizia spp.* (Mimosa, silk tree)
- *Alnus spp.* (alder)
- *Betula spp.* (birch)
- *Carpinus spp.* (hornbeam)
- *Cercidiphyllum japonicum* (Katsura tree)
- *Corylus spp.* (hazel)
- *Fagus spp.* (beech)
- *Fraxinus spp.* (ash)
- *Koelreuteria paniculata*
- *Platanus spp.* (plane)
- *Populus spp.* (poplar)
- *Prunus spp.* (cherry, plum)
- *Robinia pseudoacacia* (false acacia/black locust)
- *Salix spp.* (willow, sallow)
- *Sophora spp.* (Pagoda tree)
- *Sorbus spp.* (mountain ash/rowan, whitebeam etc)
- *Quercus palustris* (American pin oak)
- *Quercus rubra* (North American red oak)
- *Ulmus spp.* (elm)

Chalara Dieback of Ash
Ash dieback, caused by the fungus *Chalara fraxinea*, targets the ash trees *Fraxinus excelsior* (common ash) and *Fraxinus angustifolia* (narrow leaved ash). Young trees are particularly vulnerable and can be killed within one growing season of symptoms becoming visible. Older trees take longer to succumb, but still die from the infection after several seasons. *C. fraxinea* was first recorded in the UK in 2012 in Buckinghamshire and has now been reported across the UK, including in urban areas. Two confirmed cases have been reported in nurseries Wrexham, as of March 2014. Ash dieback poses a threat to 4.8% of Wrexham's urban forest.

Emerald Ash Borer
There is no evidence to date that the emerald ash borer (EAB) is present in the UK, but the increase in global movement of imported wood, wood packaging and dunnage poses a significant risk of its accidental introduction. EAB is present in Russia and is moving West and South at a rate of 30-40km per year, perhaps aided by vehicles (Straw *et* al., (2013). EAB has had a devastating effect in the USA due to its accidental introduction and could add to pressures already imposed on ash from diseases such as *C. fraxinea,* Ash dieback. Emerald Ash borer poses a potential future threat to 4.8% of Wrexham's urban forest.

Gypsy Moth
Gypsy moth (GM), *Lymantria dispar*, is an important defoliator of a very wide range of trees and shrubs in mainland Europe, where it periodically reaches outbreak numbers. It can cause tree death if successive, serious defoliation occurs on a single tree. A small colony has persisted in northeast London since 1995 and a second breeding colony was found in Aylesbury, Buckinghamshire in the summer of 2005. Aside from these disparate colonies, GMs range in Europe does not reach as far West as the UK. Some researchers suggest that the climate in the UK is currently suitable for GM should it arrive here and that it would become more so if global temperatures rise (Vanhanen *et* al., 2007). However, the spread of gypsy moth in the USA has been slow, invading less than a third of its potential range (Morin *et al*., 2005). If GM spread to Wrexham, it would pose a threat to 33.9% of Wrexham's urban trees.

Oak Processionary Moth

Established breeding populations of oak processionary moth (OPM) have been found in South and South West London and in Berkshire. It is thought that OPM has been spread on nursery trees. The outbreak in London is now beyond eradicating, whereas efforts to stop the spread out of London and to remove those in Berkshire are underway. The caterpillars cause serious defoliation of oak trees, their principal host, but the trees will recover and leaf the following year. On the continent, they have also been associated with hornbeam, hazel, beech, sweet chestnut and birch, but usually only where there is heavy infestation of nearby oak trees. The caterpillars have urticating (irritating) hairs that carry a toxin which can be blown in the wind and cause serious irritation to the skin, eyes and bronchial tubes of humans and animals. They are considered a significant human health problem when populations reach outbreak proportions, such as those in the Netherlands and Belgium in recent years. Oak Processionary Moth poses a threat to 5.8% of Wrexham's urban forest.

Phytophthora ramorum

Phytophthora ramorum (PR) was first found in the UK in 2002 and primarily affects species of oak (Turkey oak, *Q. cerris*; Red oak, *Q. rubra* and Holm oak, *Q. ilex*), beech (*F. sylvatica*) and sweet chestnut (*C. sativa*). However, it has also been known to occasionally infect European larch (*L. decidua*) and hybrid larch (*L. x eurolepsis*) and kills Japanese larch (*L. kaempferi*). Rhododendron is a major host, which aids the spread of the disease. Phytophthora ramorum poses a threat to 2.5% of Wrexham's urban forest.

Phytophthora kernoviae

Phytophthora kernoviae (PK) was first discovered in Cornwall in 2003. The disease primarily infects Rhododendron and Bilberry (*Vaccinium*) and can cause lethal stem cankers on Beech. It has been found and contained in South Wales. *Phytophthora kernoviae* is deemed to pose a risk to 6.6% of Wrexham's urban forest and affects many of Wrexham's shrub species.

Phytophthora lateralis

The main host of *Phytophthora lateralis* (PL) is Lawson Cypress (*Chamaecyparis lawsonia*). It has resulted in the decline of Lawson Cypress hedgerows, with lesions spreading up the lower stem, resulting in crown death. Although there is less than 2200 hectares of commercially grown Lawson Cypress in Britain there is a huge risk to amenity and garden Lawson Cypress. One case of PL infection has been reported and contained in Wales. *Phytophthora lateralis* is deemed to pose a risk to 1% of Wrexham's urban forest.

Red Band Needle Blight

Dothistroma (red band) needle blight is the most significant disease of coniferous trees in the North of the UK. The disease causes premature needle defoliation, resulting in loss of yield and, in severe cases, tree death. It is now found in many forests growing susceptible pine species, with Corsican pine (Pinus nigra ssp. laricio), lodgepole pine (Pinus contorta var. latifolia) and more recently Scots pine (Pinus sylvestris) all being affected. However, there are no reported cases of red band needle blight on urban trees and red band needle blight only poses a threat to less than 1% of Wrexham's urban forest.

Sweet Chestnut Blight

Sweet chestnut blight (SCB) is a fungal infection affecting sweet chestnut (*Castanea sativa* and *C. dentata*). *Q. robur, Q. petraea* and *Q.ilex* may also be infected, though in these species it is rarely fatal. The European Plant Protection Organisation also lists *Castanopsis* (evergreen beeches)*, Acer spp.* (maples/sycamore)*, Rhus typhina* (Stags Horn Sumach) and *Carya ovata* (Shagbark Hickory) as host species, though how damaging the fungus is to these species is unknown. SCB was found on nine sites across the UK in 2011 and efforts are underway to determine if SCB has reached other sites. *Castanea* species make up only 0.3% of Wrexham's urban forest, but including those species for which the risks are not yet quantified (oak, sycamore, etc.) 24% of trees in Wrexham could potentially be affected.

Pests and Diseases – Conclusions

With increased importation of wood and trees in addition to a climate that is becoming more amenable to many pests and diseases, ensuring urban forests are resilient is of paramount importance. Many of the diseases already present in the UK, such as Chalara dieback of ash and acute oak decline, are specialist diseases, affecting a small group of species in Wrexham. Protecting the urban forest as a whole against these threats can be helped by ensuring a high diversity of tree species, an area that Wrexham could significantly improve on. Other threats not yet in the UK, such as gypsy moth and Asian longhorn beetle pose a threat to many more species and could potentially devastate a diverse range of urban trees. UK wide initiatives such as plant health restrictions are designed to combat these threats, but many pests are difficult to detect (Forestry Commission, 2014). In order to protect urban forests from all pests and diseases, vigilance is key. Monitoring urban trees for signs of pests and diseases helps fast responses to eradicate pests before they are a problem and informs research targeted at combating diseases in the long term.

Table 8. Risks of emerging pests and diseases

Pest/Pathogen	Species affected	Prevalence in the Uk	Prevalence in N.Wales	Risk of spreading to N. Wales	Population at risk/%	CAVAT value of at risk trees/£ (sampled trees)	Stored carbon value of at risk trees/£
Acute oak decline	*Q. robur, Q. petraea*	SE England and Midlands	Some cases on Welsh border	High, already present	5.9	149 000	1 182 000
Asian longhorn beetle	Many broadleaf species, see above	Small outbreak in Kent	None	Medium	41.1	2 379 000	9 902 000
Chalara dieback of ash	*F. excelsior, F. angustifolia*	Cases across the UK	20 cases in Wales, eight in N. Wales	High, already present	4.8	38 000	379 000
Emerald ash borer	*F. excelsior, F. angustifolia*	None	None	Medium risk – through imported wood	4.8	38 000	379 000
Gypsy moth	Primarily *Quercus sp.*, secondarily *Carpinus betulus, F. sylvatica, C. sativa, B. pendula* and *Populus sp.*	Two outbreaks in SE England	None	Medium risk – slow spreading	33.9	1 492 000	3 681 000
Oak processionary moth	*Quercus sp.*	Three sites in S England	None	Medium – small colonies can be contained	5.8	149 000	1 182 000
Phytophthora ramorum	*Q. cerris, Q. rubra, Q. ilex, F. sylvatica, C. sativa, L. decidua, L. x eurolepsis*	Many UK sites, particularly in S Wales and SW England	Two main areas, nr. Ruthin and Ffestiniog	High – already present	2.5	420 000	1 066 000
Phytophthora kernoviae	*F. sylvatica, I. aquifolium, Q. robur, Q. ilex*[ǂ]	Several UK sites	One case in Wales, now contained	Medium	6.6	605 000	1 762 000
Phytophthera lateralis	*C. lawsonia*	Several UK sites	One case in Wales, now contained	Medium	1	20 000	40 000
Red band needle blight	*P. nigra ssp. laricio, P. contorta var. latifolia, P. sylvestris*	Several UK sites	Several sites, particularly NW Wales	High – already present	1	9 000	3 000
Sweet chestnut blight	*C. sativa, C. dentate*	Nine sites in England	None	Low	0.3	34 000	388 000

[ǂ]Shrub species are also affected, some of which were found in Wrexham: Chilean hazelnut, *Gevina avellana;* Tulip tree, *Liriodendron tulipifera;* Winters bark, *Drimys winterii; Magnolia spp.; Pieris spp.; Michelia doltsopa;* Cherry laurel, *Prunus laurocerasus;* Ivy, *Hedera helix;* Rhododendron; Bilberry, *Vaccinium sp*

Conclusions

Wrexham's urban forest is a significant asset to the area, providing valuable ecosystem services and improving the quality of life for local residents. However, though Wrexham has above average tree density (Britt and Johnston, 2008), canopy cover is only average compared to other Welsh towns (Fryer, 2014). Other urban areas of a similar size, such as Pontypool and Neath achieve much higher canopy covers, above 20%, providing a target that Wrexham could work towards. Wrexham's urban land area has a further 28% that could be planted on in the future, both on public and private land.

Comparatively to elsewhere in the UK, Wrexham has large numbers of trees more than 30cm in diameter, which are extremely valuable both in terms of ecosystem services provided (USDA, 2003) and in supporting wildlife (Lindenmayer *et al.,* 2012). However, Wrexham does not meet the 30% target of trees over 30cm in diameter, recommended for a healthy urban forest. This could be mitigated by planting more medium sized (15-30cm dbh), large growing trees (thought this may not be practical due to their relatively higher cost) and by supplementing Wrexham's flourishing population of small growing trees, such as hawthorn, with young, large growing trees. This will ensure the urban forest is maintained at a healthy level in future years.

Supplementing, rather than replacing small growing trees with large growing trees will ensure that in addition to the ecosystem services provided by large growing trees, the habitats provided by small growing trees, such as hawthorn, will be retained. It is not practical to plant large growing trees everywhere, so due consideration for the appropriate trees for individual sites must be considered.

Three species (sycamore, hawthorn and silver birch) made up a large proportion of Wrexham's trees, all exceeding 10%. It is recommended that a higher diversity of trees is planted to ensure the resilience of Wrexham's urban forest to pests and diseases, both on public and private land.

The value of Wrexham's trees as a structural asset is extremely high, with replacement costs totalling around £1 billion and the carbon stored in these trees worth £14 million. Valuing urban forests in terms of asset value is a technique that could be utilised by councils in decision making, particularly with regards to planning development projects where the loss of trees is considered.

Protecting sites of particular value could also be facilitated by the results. Cemeteries were found to contain trees with the highest asset value, despite cemeteries representing only a small portion of land use. This was due to a combination of factors. It contained very old trees and a mix of unusual species. All the trees were also accessible to the public and a few trees were very large with high replacement costs. Identifying these factors serves as a tool for use in protecting sites of special value but can also be used as an example where councils would like to raise the value of other areas, perhaps in council owned parks. Using Wrexham cemetery as a case study, a few simple steps could be taken to provide value to urban forests:

- Ensuring the protection of trees so that they may live to maturity
- Considering more visually appealing versions of common trees
- Considering unusual species
- Keeping diversity high – Wrexham cemetery achieves this by containing small growing trees beneath large ones, thus supporting more trees overall

In addition to the asset value of trees, trees provide extra annual value by providing ecosystem services. This delivers on-going and, in some cases, annually increasing benefits and potentially saves expenditure elsewhere, again facilitating decision making processes in terms of providing infrastructure in Wrexham. For example, tree planting or increasing pervious surface area could be a more viable solution to local flooding issues than extending existing sewer networks, with the added benefit of the other ecosystem services provided by trees and green spaces. The values provided in this report should aid in this decision making process.

Information in this report can also be used to shape policy or local targets. The carbon sequestered annually by Wrexham's trees was significant at 1 300 tonnes per year. This can be compared to many carbon emitting practices, such as car use. However, this could also be used to inform tree planting to, for example, offset all car emissions by a certain date, employing a tangible and therefore more achievable goal into local policy.

In addition, this report has the potential to raise the public profile of trees, helping to educate Wrexham's residents about the benefits their trees can provide, with the hope of reducing the animosity directed at initiatives such as TPO's, designed to protect trees for the benefit of society overall.

This study does have limitations, with not all benefits provided by trees quantified, including the effect trees have on noise pollution and secondary effects of pollutants, such as acid rain. The urban forest in Wrexham is, therefore, far more valuable than stated in this report. Future developments enable these extra benefits to one day supplement this report, giving a better overall picture.

This study is also limited in the fact that it is a snapshot of the forest at one moment in time. Monitoring of the urban forest using the same technique will allow annual variations to be taken into account and could, in the long term, inform us about dynamic processes such as climate change, allowing a more robust long-term picture to be built up.

Overall, Wrexham's urban forest considerably improves the lives of inhabitants and visitors and should be valued as an asset. The urban forest can be used as a functional tool to ensure our dense urban spaces are more habitable and sustainable in the long-term. Planning practices and policy should reflect this, valuing trees as an integral part of our urban landscape. It is recommended that an i-Tree survey is conducted every 5-10 years to support the management and planning of Wrexham's urban forest.

Simpson, 2010

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Appendix I. Detailed Methodology

i-Tree Eco Models and Field Measurements

i-Tree Eco is designed to use standardised field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak and Crane, 2000), including:

- **Urban forest structure** (e.g., species composition, tree health, leaf area, etc.).
- **Amount of water intercepted by vegetation**
- **Amount of pollution removed** hourly by the urban forest and its associated per cent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<10 microns; PM_{10} and <2.5 microns; $PM_{2.5}$).
- **Total carbon stored and net carbon annually sequestered** by the urban forest.
- **Structural value of the forest**, as well as the value for air pollution removal and carbon storage and sequestration.
- **Potential impact of potential emerging pests and diseases**

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

To calculate the volume of stormwater intercepted by vegetation an even distribution of rain is assumed. The calculation is split into three stages:

1. The volume of water intercepted by vegetation
2. The volume of water dripping from vegetation once their canopy has reached saturation, minus water evaporation from leaf surfaces during the rainfall event
3. The volume of water that evaporates from leaf surfaces after a rainfall event

The same process is then applied to water reaching impervious ground, with saturation of the holding capacity of the ground causing surface runoff. Pervious cover is treated similarly, but with a higher storage capacity over time. See Hirabayashi (2013) for full methods.

Processes such as the effect tree roots have on drainage through soil are not calculated as part of this model.

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 (Nowak, 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone and sulphur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi, 1988; Baldocchi et al., 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser, 1972; Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 per cent re-suspension rate of particles back to the atmosphere (Zinke, 1967).

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

Structural values were based on valuation procedures of the US Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information (Nowak et al., 2002), in this case calculated using standard i-Tree inputs such as per cent canopy missing.

CAVAT valuation takes into account the same health assessments but is based on field notes rather than i-Tree collected data. It also takes into account the amenity value of the tree i.e. a higher score is given to trees that are visible to the public. Special considerations such as whether a tree is a champion tree or an unusual species also increase a trees score. For more detailed methodology, see http://www.ltoa.org.uk/resources/cavat.

US Externality and UK Social Damage Costs

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

In the UK, however, the appropriate way to monetise the carbon sequestration benefit is to multiply the tonnes of carbon stored by the non-traded price of carbon (i.e. this carbon is not part of the EU carbon trading scheme). The non-traded price is not based on the cost to society of emitting the carbon, but is based on the cost of not emitting the tonne of carbon elsewhere in the UK in order to remain compliant with the Climate Change Act. The unit values used were based on those given in DECC (2011). This approach gives higher values of carbon than the approach used in the United States, reflecting the UK Government's response to the latest science, which shows that deep cuts in emissions are required to avoid the worst effects of climate change.

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

There are three levels of 'sensitivity' applied to the air pollution damage cost approach: 'High', 'Central' and 'Low'. This report uses the 'Central' scenario based on 2010 prices.

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

The key effects that have not been included are:

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

CAVAT Analysis

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

To reach a CAVAT valuation the following was obtained:

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

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

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

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

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

For trees found in open spaces, trees were divided into those with 100% exposure to light and those that did not. On the basis that trees in open spaces are less intensively managed, an 80% functionality factor was applied to all individual open grown trees. For those trees without 100% exposure to light, a 60% factor was applied to those growing in small groups and a 40% factor applied to those growing in large groups. An overall figure could have been applied to all non-highway trees, but it would not reflect how significant a proportion of the population trees in groups were.

SULE assessment was intended to be as realistic as possible and was based on existing circumstances. For full details of the method refer to LTOA (2010).

Appendix II. Species Importance List

Fig. A1. Importance values for all species encountered during the Wrexham survey

Rank	Species	Population/%	Leaf area/%	IV
1	*Acer pseudoplatanus*	16.10	29.30	45.40
2	*Betula pendula*	11.26	7.41	18.66
3	*Crataegus monogyna*	12.04	4.89	16.93
4	*Quercus robur*	3.53	5.47	9.00
5	*Tilia cordata*	2.09	6.74	8.84
6	*Corylus avellana*	4.19	4.52	8.71
7	*Fraxinus excelsior*	4.84	3.76	8.60
8	*Salix spp.*	4.45	3.54	7.99
9	*Prunus avium*	4.45	3.23	7.68
10	*Cupressocyparis leylandii*	4.71	2.52	7.23
11	*Salix caprea*	3.67	3.42	7.08
12	*Ulmus glabra*	2.75	2.66	5.41
13	*Fagus sylvatica*	1.96	3.17	5.13
14	Dead/unidentifiable hardwoods	3.93	0.00	3.93
15	*Alnus glutinosa*	2.49	1.44	3.92
16	*Sambucus nigra*	3.14	0.68	3.82
17	*Quercus petraea*	2.23	1.14	3.36
18	*Acer platanoides*	0.92	2.17	3.09
19	*Platanus x acerifolia*	0.13	1.98	2.11
20	*Malus spp*	1.18	0.77	1.95
21	*Castanea sativa*	0.26	1.54	1.80
22	*Ilex aquifolium*	0.92	0.78	1.70
23	*Taxus baccata*	0.26	1.27	1.53
24	*Malus domestica*	0.79	0.63	1.42
25	*Cupressus spp.*	0.92	0.44	1.36
26	*Fagus sylvatica 'Purpurea'*	0.13	1.20	1.33
27	*Sorbus aucuparia*	0.92	0.40	1.32
28	*Cupressocyparis spp.*	0.65	0.61	1.26
29	*Acer spp.*	0.39	0.58	0.97
30	*Acer campestre*	0.26	0.70	0.96
31	*Sorbus thuringiaca*	0.13	0.55	0.69
32	*Laburnum anagyroides*	0.26	0.39	0.65
33	*Picea abies*	0.26	0.21	0.48
34	*Betula spp.*	0.26	0.20	0.46
35	*Prunus domestica*	0.39	0.07	0.46
36	*Ulmus japonica*	0.26	0.19	0.45
37	*Salix x sepulcralis Simonkai*	0.13	0.32	0.45
38	*Populus nigra*	0.26	0.18	0.44
39	*Pyrus spp.*	0.26	0.17	0.43
40	*Crataegus x lavallei*	0.26	0.09	0.35
41	*Pinus strobus*	0.26	0.08	0.34
42	*Pinus sylvestris*	0.13	0.11	0.24
43	*Syringa vulgaris*	0.13	0.10	0.23

Rank	Species	Population/%	Leaf area/%	IV
44	*Sorbus torminalis*	0.13	0.08	0.21
45	*Larix decidua*	0.13	0.07	0.20
46	*Prunus spp.*	0.13	0.06	0.19
47	*Carpinus betulus*	0.13	0.06	0.19
48	*Cornus spp.*	0.13	0.04	0.18
49	*Tilia platyphyllos*	0.13	0.04	0.17
50	*Cotinus coggygria*	0.13	0.02	0.15
51	*Pinus spp.*	0.13	0.02	0.15
52	*Rhus hirta*	0.13	0.02	0.15
53	*Cupressus macrocarpa*	0.13	0.01	0.14
54	*Quercus spp.*	0.13	0.00	0.13

Appendix III. Environmental services by species

Table A2. Environmental services provided by all trees encountered in Wrexham

Species	Number of Trees	Carbon/ ¹mt	Gross Seq/ ¹mt/yr	Net Seq/ ¹mt/yr	Leaf Area/ km2	Leaf Biomass/ ¹mt	Stored carbon/ t	Value/£ (non-traded, central)
Acer pseudoplatanus	58599	18947.48	626.25	545.43	8.51	595.14	69474	3960023
Crataegus monogyna	43830	1898.95	143.55	121.92	1.42	178.44	6963	396880.6
Betula pendula	40972	4243.27	269.92	245.81	2.15	127.77	15559	886843.4
Fraxinus excelsior	17627	1814.12	84.3	72.75	1.09	116.09	6652	379151.1
Cupressocyparis leylandii	17151	326.23	37.31	35.94	0.73	114.4	1196	68182.07
Prunus avium	16198	1353.76	73.17	15.93	0.94	72.52	4964	282935.8
Salix spp.	16198	3768.95	82.78	4.73	1.03	63.53	13819	787710.6
Corylus avellana	15245	629.19	60.23	58.3	1.31	91.2	2307	131500.7
Unidentified Hardwood	14292	3429.61	2.38	-589.68			12575	716788.5
Salix caprea	13340	2425.68	88.92	62.58	0.99	62.82	8894	506967.1
Quercus robur	12863	4793.9	171.51	155.96	1.59	105.72	17578	1001925
Sambucus nigra	11434	261.54	24.05	20.46	0.20	14.83	959	54661.86
Ulmus glabra	10005	913.17	47.34	37.26	0.77	52.69	3348	190852.5
Alnus glutinosa	9052	2711.36	92.05	59.2	0.42	30.44	9942	566674.2
Quercus petraea	8099	854.37	42.17	35.33	0.33	32.53	3133	178563.3
Tilia cordata	7623	2773.8	79.19	73.39	1.96	146.68	10171	579724.2
Fagus sylvatica	7146	2408.25	84.1	70.12	0.92	46.05	8830	503324.3
Malus spp	4288	324.48	26.2	24.67	0.22	19.33	1190	67816.32
Acer platanoides	3335	631.64	29.48	27.18	0.63	34.03	2316	132012.8
Cupressus spp.	3335	232.02	11.77	10.86	0.13	20.12	851	48492.18
Ilex aquifolium	3335	394.54	26.32	24.59	0.23	30.41	1447	82458.86
Sorbus aucuparia	3335	78.13	10.14	9.57	0.12	9.28	286	16329.17
Malus domestica	2858	324.01	23.25	22.11	0.18	15.9	1188	67718.09
Cupressocyparis spp.	2382	188.77	8.19	7.58	0.18	27.72	692	39452.93
Acer spp.	1429	159.05	9.55	8.82	0.17	9.41	583	33241.45
Prunus domestica	1429	69.75	4.71	3.21	0.02	1.48	256	14577.75
Acer campestre	953	407.86	15	13.42	0.20	11.49	1495	85242.74

Species	Number of Trees	Carbon/ [1]mt	Gross Seq/ [1]mt/yr	Net Seq/ [1]mt/yr	Leaf Area/ km2	Leaf Biomass/ [1]mt	Stored carbon/ t	Value/£ (non-traded, central)
Betula spp.	953	131.88	11.33	10.79	0.06	3.56	484	27562.92
Castanea sativa	953	1857.3	45.18	38.45	0.45	31.26	6810	388175.7
Crataegus x lavallei	953	7.35	1.39	1.38	0.03	1.93	27	1536.15
Laburnum anagyroides	953	213.08	11.2	10.37	0.11	8.4	781	44533.72
Picea abies	953	42.52	3.32	2.92	0.06	10.38	156	8886.68
Pinus strobus	953	44.94	3.87	3.44	0.02	1.5	165	9392.46
Populus nigra	953	2547.14	39.79	16.18	0.05	3.84	9340	532352.3
Pyrus spp.	953	81.78	7.88	7.55	0.05	3.59	300	17092.02
Taxus baccata	953	255.56	7.69	6.77	0.37	57.81	937	53412.04
Ulmus japonica	953	69.57	6.95	6.66	0.06	3.79	255	14540.13
Carpinus betulus	476	67.12	3.71	3.55	0.02	0.96	246	14028.08
Cornus spp.	476	9.07	2.02	1.98	0.01	0.74	33	1895.63
Cotinus coggygria	476	13.51	2.47	2.41	0.01	0.49	50	2823.59
Cupressus macrocarpa	476	3.35	0.77	0.75	0.00	0.69	12	700.15
Fagus sylvatica 'Purpurea'	476	834.29	16.18	13.01	0.35	17.4	3059	174366.6
Larix decidua	476	2.35	0.27	0.27	0.02	1.03	9	491.15
Pinus spp.	476	24.12	1.86	1.76	0.01	0.55	88	5041.08
Pinus sylvestris	476	14.16	1.38	1.37	0.03	3.02	52	2959.44
Platanus x acerifolia	476	2740.24	9.05	-1.19	0.57	26.39	10048	572710.2
Prunus spp.	476	62.71	3.87	3.72	0.02	1.21	230	13106.39
Quercus spp.	476	4.68		-1.29			17	978.12
Rhus hirta	476	5.88	1.54	1.51	0.01	0.49	22	1228.92
Salix x sepulcralis Simonkai	476	55.38	4.87	4.65	0.09	5.96	203	11574.42
Sorbus thuringiaca	476	184.25	8.69	7.97	0.16	12.8	676	38508.25
Sorbus torminalis	476	124.99	5.34	4.64	0.02	1.83	458	26122.91
Syringa vulgaris	476	6.44	1.63	1.6	0.03	2.78	24	1345.96
Tilia platyphyllos	476	5.46	0.74	0.73	0.01	0.73	20	1141.14

[1]mt is Metric ton/tonne

Glossary of Terms

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

Broadleaf species – For example, alder, ash, beech, birch, cherry, elm, hornbeam, oak, other broadleaves, poplar, Spanish chestnut, and sycamore

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

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

Crown – The crown of a plant refers to the totality of the plant's aboveground parts, including stems, leaves, and reproductive structures

Defoliator – (Defoliators) Pests that chew portions of leaves or stems, stripping of chewing the foliage of plants. (Leaf Beetles, Flea Beetles, Caterpillars, Grasshoppers, etc.)

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

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

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

Ecosystem services - The benefits people obtain from ecosystems

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

Leaf area index - Leaf Area Index (LAI) is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows

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

Meteorological - Pertaining to meteorology or to phenomena of the atmosphere or weather

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

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

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

Re-suspension - The remixing of sediment particles and pollutants back into the water by storms, currents, organisms, and human activities, such as dredging

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

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

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

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

Tree-canopy - the aboveground portion of a plant community or crop, formed by plant crowns

Tree dry-weight - The plant, animal, or other material containing the chemical of interest is dried to remove all water from the material. The amount of the chemical found in subsequent analysis is then expressed as weight of chemical divided by weight of the dried material which once contained it

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

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

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Simon Morath, Michael Sears and Rudy Genazzi, on site (Simpson, 2013)