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Valuing Urban Trees in the Tawe Catchment

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

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

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

In association with:

Cyfoeth Naturiol Cymru
Natural Resources Wales

Neath Port Talbot County Borough • Bwrdeistref Sirol Castell-nedd Port Talbot

City and County of Swansea
Dinas a Sir Abertawe

Dŵr Cymru
Welsh Water

Powys

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Front Cover: courtesy of Dafydd Fryer, 2015

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Executive Summary

Urban forests provide a range of services, often termed ecosystem services, that help alleviate problems associated with urbanisation. Trees improve local air quality, capture carbon, reduce flooding and cool urban environments. They provide habitat for animals, and can improve social cohesion in communities. Ecosystem service provision is directly influenced by management actions that affect the overall structure of an urban forest.

The first step to improve the management of an urban forest is to better understand its current structure, composition and distribution in order to obtain a baseline from which to set goals and to monitor progress. By measuring the structure of the urban forest (the tree species present, their size and condition), the benefits of the urban forest can be determined and the value of these benefits calculated and expressed in monetary terms. Valuing services provided by the urban trees of the Tawe catchment could allow Swansea, Powys and Neath Port Talbot Councils and Natural Resources Wales (NRW) to increase the profile of the urban forest thereby helping to ensure its value is maintained and improved upon.

The Tawe catchment, as described in this study, is spread across eight separate urban areas with a total area of 6,995 ha. In order to gain a better understanding of the urban trees in the Tawe catchment and to value the services they provide, an i-Tree Eco survey was undertaken in the summer of 2014. i-Tree Eco is a model developed by the US Forest Service to measure a range of ecosystem services provided by urban trees. This study was funded by NRW and the survey was carried out by TACP.

This report presents a baseline quantitative assessment of the air pollution removal, carbon storage and sequestration, rainfall interception and public amenity of the urban forest of the Tawe catchment, and is accompanied with detailed information on the forest's structure and composition. Residents in the Tawe catchment benefit significantly from urban trees, including the **provision of ecosystem services worth £1,720,000 per year**. This value excludes the many ecosystem services provided by trees that are not currently assessed by i-Tree Eco, including cooling local air temperatures and reducing noise pollution. Therefore, this value is a conservative estimate of the ecosystem services provided. This study captures a snapshot-in-time of the urban forest. It does not consider how the urban forest has changed over time or the reasons for this. Decisions on how the structure and composition of the urban forest of the Tawe catchment should change in the future or how to ensure that it is resilient to the effects of a changing climate are beyond the scope of this report, though this study goes a long way to providing the necessary baseline data required to inform such decision making.

Key Results

The urban forest of the Tawe catchment in 2014:

- had over **530,000 trees**, resulting in an average **urban tree density of 76 trees per hectare**, this is above existing estimates for other areas in the UK
- had a **16% urban tree cover**, equal to an area of 1,119 ha. The trees were primarily found in **parks**, on **residential land** and on **vacant land**
- had a **low proportion of large trees** compared to previous i-Tree Eco studies conducted in the UK, and would benefit from more medium and large sized trees
- had up to **24% of urban space available** to plant trees or shrubs
- included **88 tree and shrub** species, recorded across 12 land use categories
- had **common alder, goat willow** and **downy birch** as the top three tree species

The trees in **the Tawe catchment** in 2014:

- intercept an estimated **252 million litres of water** every year, equivalent to an estimated **£333,900** in sewerage charges avoided
- remove an estimated **136 tonnes of airborne pollutants** each year, worth more than **£715,500** in damage costs
- remove an estimated **3,000 tonnes of carbon** from the atmosphere each year, this amount of carbon is estimated to be **worth £671,000**
- store an estimated **102,000 tonnes of carbon**, this amount of carbon is estimated to be **worth £23.1 million**
- have a **replacement value** of **£234 million**
- have an **asset value** of **£816 million**, an evaluation based on public amenity.

Key Conclusions

- Species mix in the urban forest should be diversified to build resilience to pests and diseases and improve ecosystem service provision by Tawe catchment trees
- The Tawe catchment urban forest should be managed to increase the number and diversity of mature large stature trees; these are currently poorly represented yet provide proportionally more ecosystem services than small stature trees
- Local development plans should seek to conserve the trees on vacant land as they deliver a significant proportion of the ecosystem services of the urban forest
- Assessment of the urban forest should be repeated in five years to assess change.

Introduction

Urban trees provide a range of services that benefit humans, "ecosystem services". A first step to improve the management of an urban forest and maximise the benefits that it provides to humans is to undertake an urban forest assessment and quantify some of the ecosystem services provided. This can be done by using models such as i-Tree Eco, developed by the US i-Tree Cooperative[1]. i-Tree Eco has been used successfully in over 100 cities globally, has been tested for its suitability for use in the UK (Rogers et al. 2012) and has been rated as fit-for-purpose for valuing green infrastructure in the UK (Natural England 2013).

In this report, we present the findings of an i-Tree Eco survey undertaken in the Tawe catchment, South Wales in 2014. In this section, we present an introduction to the core concepts of natural capital and ecosystem service provision required to understand the i-Tree approach to urban forest assessment.

Natural Capital and Ecosystem Service Provision

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

The ecosystem services provided to society by urban trees are introduced below:

- urban trees can play an important role in improving the health and comfort of urban residents. They provide this benefit either by absorbing and filtering pollutants and improving local air and water quality (Bolund & Hunhammar 1999), by reducing air temperatures and the so called urban heat island effect (Akbari et al. 2001) and by helping reduce stress levels and improve recovery time from illness (Ulrich 1979)
- urban trees also provide economic benefits. They store carbon, absorbing it into their tissues, helping to offset carbon emissions produced by other urban activities (Nowak et al. 2008). Urban trees also alleviate flash flooding, a problem that can cost cities millions of pounds each year (Bolund & Hunhammar 1999). Commercial and private property value is also increased with the addition of trees (Forestry Commission 2010)

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

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

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

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

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

Table 1 shows that many of the ecosystem services provided by urban trees are not quantified or valued by i-Tree Eco. **The value of the Tawe catchment urban forest presented in this report should therefore be recognised as a conservative estimate** of the value of the full range of benefits that this urban forest provides to the residents and visitors to the Tawe catchment. It is also important to recognise that:

- the v5 i-Tree Eco model used in this study does not calculate projected changes in the urban forest over time or under different management regimes. It rather provides a snapshot-in-time picture on size, composition and condition of an urban forest. Only through comparison to previous i-Tree Eco studies, or studies using a comparable data collection method, we can assess how the urban forest is changing

- air pollution data must be provided together with the field data for computation. As this data has to come from a single air quality station, monitoring all of the air pollutants of interest and span one full calendar year, data used for modelling is not always obtained from the nearest located air quality station. For example the nearest station(s) may only monitor a sub-set of pollutants required
- i-Tree Eco is a useful tool providing essential baseline data required to inform management and policy making in support of the long term health and future of an urban forest, but does not of itself report on these factors
- i-Tree Eco demonstrates which tree species and size class(es) are currently responsible for delivering which ecosystem services. Such information does not necessarily imply that these tree species should be used in the future. Planting and management must be informed by:
    - considerations specific to a location, such as soil quality, quantity and available growing space
    - the aims and objectives of the planting or management scheme
    - local, regional or national policy objectives
    - current climate, with due consideration given to future climate projections
    - guidelines on species composition and size class distribution for a healthy resilient urban forest.

Opportunities

The information in this report allows decision makers to:

- raise the profile of the urban forest as a key component of green infrastructure that provides many benefits and services to those who live and work in the Tawe catchment
- manage the Tawe catchment urban forest as an asset, with appreciable return
- plan for and finance expansion of canopy cover
- redress imbalance in species mix and age composition profiles; such changes would also help create a forest that is more resilient to the impacts of climate change
- identify risks to the tree population such as through pests and diseases, and to plan accordingly
- establish new policy to protect and expand all aspects of the Tawe catchment urban forest, including both under private and public ownership.

Links

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

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

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

Box 1. What difference can i-Tree make?

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

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

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

Legislative Context in Wales

By Barbara Anglezarke (NRW)

The work to promote the wide-ranging benefits of urban woodlands and trees is now strongly underpinned by three important pieces of legislation.

Wellbeing of Future Generations (Wales) Act 2015

The Act features seven wellbeing goals with national indicators and milestones. It requires public bodies to put long-term sustainability at the forefront of their thinking, and work with each other along with other relevant organisations (such as sector groups) and the public to prevent and tackle problems. Planting and looking after trees is a key way in which we can help to safeguard the health and wellbeing of those who come after us. Public bodies will need to work towards five criteria that make up the Act's Sustainable Development Principle, which in turn will help meet the seven goals.

- **Long-term thinking** - balancing short-term needs with safeguards to meet long-term needs.
- **Prevention** - actions to prevent problems getting worse.
- **Integration** - considering how your objectives may impact on those of others.
- **Collaboration** - working with other bodies that can help you meet your goals.
- **Involvement** - involving people and communities with an interest in helping you meet your objectives, and reflecting the diversity of the people in your area.

Public bodies will need to demonstrate how they are working towards the goals. This will be through publishing wellbeing statements and responding to the Future Generations Commissioner. This will be monitored and scrutinised by the Auditor General Wales.

Environment Bill

The Bill links very closely with the Wellbeing of Future Generations Act, and it's anticipated that it will receive Royal Assent in mid-2016. It will puts in place the primary legislation needed to manage Wales's natural resources sustainably, and provides a framework for area based natural resource planning - strengthening the duty on public bodies to conserve biodiversity, and requiring NRW to lead on the development of Area Statements to translate national targets into local action. It will include a new duty for public bodies to maintain and enhance biodiversity.

Woodlands for Wales 2009 – the Welsh Government's Woodland Strategy

The Welsh Government sets out here its aspirations for urban woodlands and trees and set clear objectives in the associated Action Plan. The aim is that trees and woodlands play a greater and more valued role in towns and cities, improving quality of life and surroundings for people who live in urban areas – delivering a full range of benefits.

Sustainable Management of Natural Resources - the Tawe Catchment Trial

By Jerry Griffiths (NRW)

The Tawe Catchment Trial is designed to show how to deliver the Welsh Government's Environment Bill. It will look at how we manage the area's natural resources to deliver multiple benefits for people, the economy and environment. Projects like this i-Tree Eco study are important parts of the trial – they will help us to gather evidence, engage with partners and identify opportunities for sustainable management of natural resources (SMNR) in the catchment. i-Tree Eco is important for NRW to build relationships with local authorities and provide useful evidence that we can use to effect change in the catchment. In this case, we anticipate that the i-Tree Eco findings can lead to greater appreciation of urban trees, and the value of the ecosystem services they provide. We hope this leads to greater protection and maintenance of existing urban trees and the planting of new ones.

Why the Tawe Catchment?

The Tawe catchment is a fascinating and beautiful place with a vibrant history it ranges from the wild uplands of the Brecon Beacons to the heart of Abertawe (Swansea), which literally means mouth of the Tawe and is Wales' second largest city. The Tawe has carried Swansea through the ages and the lower reaches bear the scars of the areas industrial past. The uplands offer a high conservation value with numerous designated sites including Special Areas of Conservation, Sites of Special Scientific Interest and the Brecon Beacons National Park. Following the demise of manufacturing, tourism has become increasingly important to the local economy and the area provides a diverse offering of recreational activities and beautiful landscapes. The SMNR Tawe Catchment Trial area is shown in Figure 1.

The NRW Approach:

There are three strands to NRW's work in the Tawe Catchment Trial, these are:

- Collecting evidence – Evidence is important so we can understand the key issues in the catchment and base our decision making on sound science
- Delivering projects – Through Welsh Government's Nature Transition Fund, we are delivering 10 projects that will help us to understand what is required to deliver area based planning locally and showcase how, by working with others we can deliver multiple benefits for the environment, people and the economy
- Engaging stakeholders – We are working with a wide range of stakeholders to understand what the key issues and opportunities are for managing our natural resources in the Tawe catchment. We are holding a number of consultation events throughout the catchment and will be holding a conference to inform, inspire and involve people in Natural Resource Management.

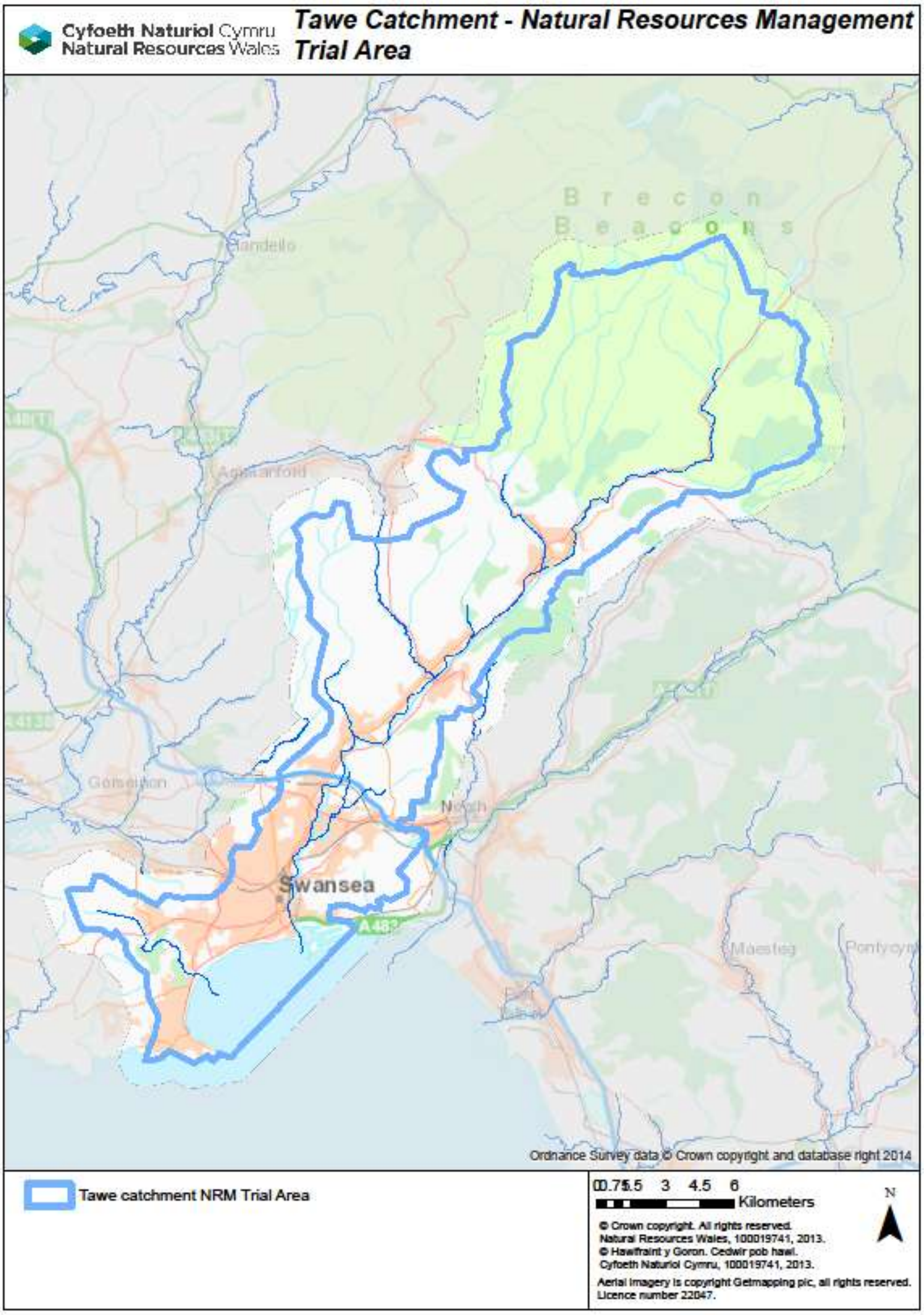

Figure 1. The SMNR Tawe Catchment Trial area.

Methodology

i-Tree Eco uses a plot based method of sampling, with data recorded from a number of plots across a study area that are extrapolated to represent the area as a whole. Previous similar canopy cover studies have been based on aerial photography (John Clegg Consulting Ltd, 2007). However, the plot based method using 252 plots selected from a randomised grid covering the study area results in higher resolution data and includes information on individual trees. The Tawe catchment, as described in this study, is spread across eight separate urban areas of the County and City of Swansea, Powys County and Neath Port Talbot County Borough (CB) (Figure 2). The urban boundaries adopted are those defined in Tree Cover in Wales' Towns and Cities (TCWTC; Fryer 2014). Of the 252 plots, 181 were in the City of Swansea, 51 in Neath Port Talbot CB and 20 in Powys County.

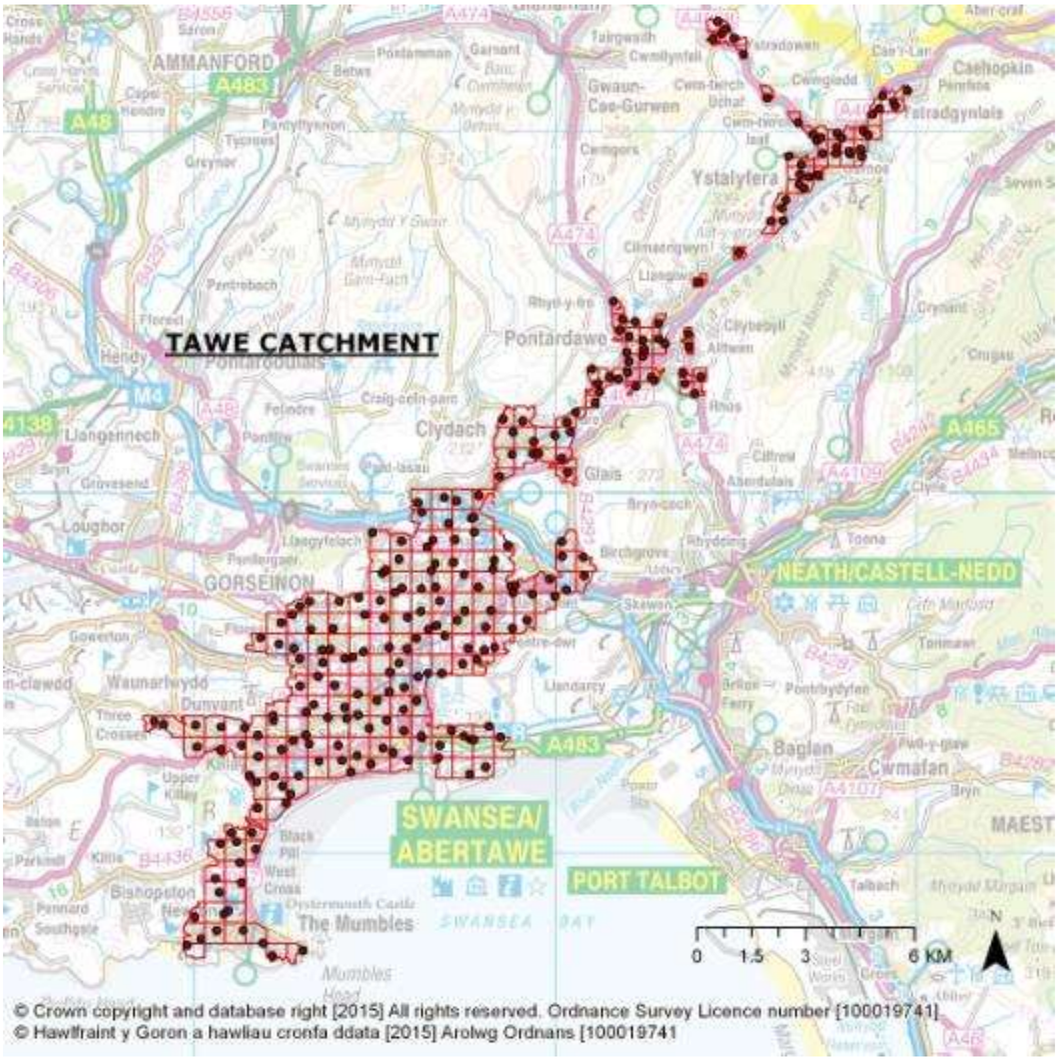

Figure 2. The Tawe catchment study area. The sample grid and randomised plots are also shown. (basemap: ©OpenStreetMap contributors)

The randomised grid 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 edge of the sample area were only allocated a sample plot if at least 50% of the grid was within the sample area.

The total sample area was 6,995 Ha, resulting in a sample every 28 ha, similar to the sample density used in the Torbay, i-Tree Eco study (every 26 ha). The proportion of plots falling into each of the different land uses is given in Figure 3.

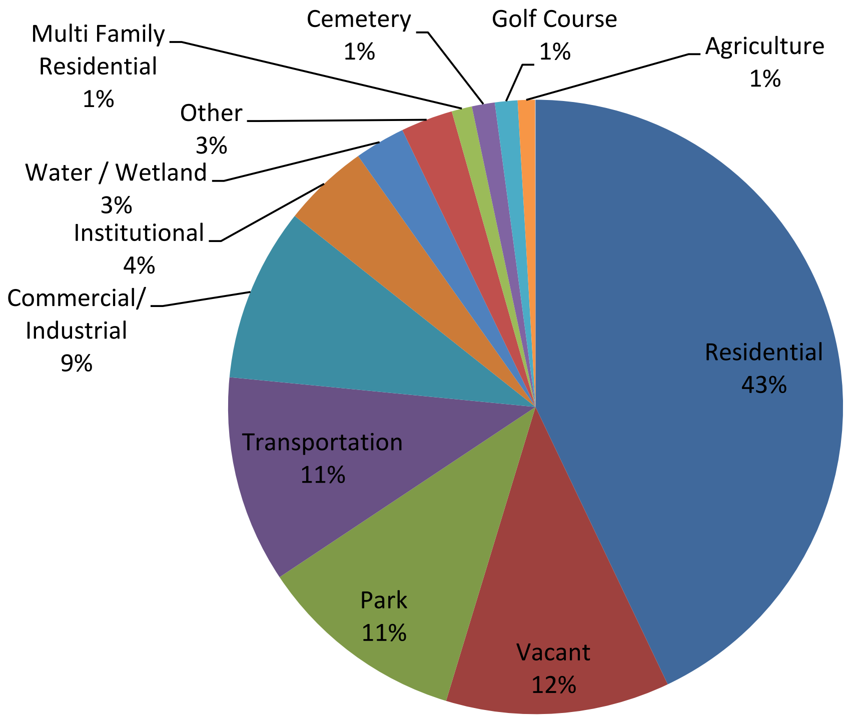

Figure 3. Proportion of plots falling into each of the different land uses (For a definition of land-uses see Appendix 1: Table 16)

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

Each plot covered 0.04 ha and from each was recorded:

- the type of land use, e.g. park, residential
- the percentage distribution of cover present in the plot e.g. grass, tarmac
- the percentage of the plot that could have trees planted in it[2]
- information about trees[3], including the
    - number of trees and their species
    - size of the trees including height, canopy spread and diameter at breast height (DBH) of trunk
    - condition of the trees including the fullness of the canopy
    - amount of light exposure the canopy receives
    - amount of impermeable surface (e.g. tarmac) under the tree
- Information about shrubs[4], including the
    - number of shrubs and their species
    - size and dimensions of the shrubs

Data collected in the field was submitted to the US Forest Service for use in the i-Tree Eco model. i-Tree Eco calculates the species and age class structure, biomass and leaf area index of the urban forest. This data is then combined with local climate, phenology and air pollution data to produce estimates of a number of ecosystem services (Table 2) and adjusted for UK Benefit Prices to assess their current and future value.

Standard i-Tree outputs are currently designed for a US audience. Thus, raw valuations are reported in terms of how ecosystem services are valued in the US and, in addition, values are reported in US dollars. In this and other UK studies, ecosystem services were also valued using the methods outlined by the UK Treasury - details are provided in the Summary of Calculations sub-section, below, and in the results sections.

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

[3] In this study, a "tree" is defined as a woody plant with a trunk diameter at breast height (DBH) that is greater than 7 cm (DBH > 7 cm)

[4] For the purposes of this study, a "shrub" is defined as a plant, woody or otherwise, with a total height over 1 m but a DBH of less than 7 cm

Weather Data

Weather data was for the year 2013, recorded at Cardiff Bute Park weather station, approximately 55km east of the sample area. NO_2 (2013), CO (2013), PM's 10 (2013) and 2.5 (2013), O_3 (ozone) (2013) and SO_2 (2013) were recorded at the Cardiff Centre station on Frederick Street, Cathays. All pollution data was obtained from www.uk-air.defra.gov.uk.

Table 2. Outputs calculated based on field collected data.

Urban forest structure and composition	Species diversity, canopy cover, age class, condition, importance and leaf area Urban ground cover types % leaf area by species
Ecosystem services	Air pollution removal by urban trees for CO, NO_2, SO_2, O_3, PM_{10} and $PM_{2.5}$ and value in £ Annual carbon sequestered and value in £ Rainfall interception and avoided sewerage charges value in £ Energy use by domestic buildings
Replacement costs and functional values	Replacement cost based upon structural value in £ (CTLA - Council of Tree and Landscape Appraisers Method) *Replacement cost based upon amenity value in £ (a CAVAT - Capital Asset Value for Amenity Trees - assessment)* Current carbon storage value in £
Habitat provision	*Pollinating insects* *Insect herbivores*
Potential insect and disease impacts	Acute oak decline*,* Asian longhorn beetle*,* bleeding canker of horse chestnut, *chalara* dieback of ash*,* emerald ash borer*,* giant polypore*,* oak processionary moth*, Phytophthora alni Phytophthora ramorum, Phytophthora kernoviae, Phytophthora lateralis, Dothistroma (*red band) needle blight*, spruce bark beetle*

Italic entries denote non-standard i-Tree outputs conducted by the authors

Phenology Data

Leaf-on and leaf-off dates are required within the i-Tree Eco model for quantifying ecosystem service provision. Mean average leaf-on/leaf-off dates were calculated using datasets from the UK's Nature's Calendar phenology records (Woodland Trust 2014). 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 five year period (2010-2014) 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 (2009-2013) to provide an average date for the leaf off event. The average date calculated for leaf on was April the 18th. The average date calculated for leaf off was November the 4th. Therefore, the total number of days that trees were in leaf was taken to be 201 days.

Replacement Cost and Amenity Value

i-Tree Eco provides replacement costs for trees based on The CTLA (Council of Tree and Landscape Appraisers 1992) valuation method. The Capital Asset for Amenity Trees (CAVAT) (Nielan/LTOA 2010) method was also used in the current study. CAVAT has been developed in the UK and has been used by councils to support planning decisions. CAVAT provides a value for trees in towns, based on an extrapolated and adjusted replacement cost. This value relates to the public amenity that trees provide, rather than their worth as property (as per the CTLA method). Particular differences to the CTLA trunk formula method include the addition of the Community Tree Index (CTI) factor, which adjusts the CAVAT value to take account of greater amenity in areas of higher population density, using official population figures. An amended CAVAT full method was chosen to assess the trees in this study, developed in conjunction with Chris Neilan – the primary author of CAVAT. A detailed methods section for both i-Tree Eco calculations and additional calculations, including CAVAT, is provided in Appendix I.

Pests and Diseases

Pest susceptibility was assessed using information on the number of trees within pathogen/pest target groups and the prevalence of the pest or disease within the UK. A risk matrix was devised for determining the potential impact of priority pests and diseases, should they become established in the urban tree population of the Tawe catchment. The risk matrix was adapted for use where a pest or disease targets a single genus and multiple species.

Habitat Provision

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

Summary of Calculations

Number of trees: Total number of estimated trees extrapolated from the sample plots.

Canopy cover: Total tree and shrub cover taken from direct measurements within plots.

Most common species were found based on field observations.

Pollution removal value: Calculated based on the UK social damage costs (UKSDC) and the US externality cost prices (USEC) where UK figures are not available; and these were: £1,619 per metric ton CO (carbon monoxide - USEC), £11,397 per metric ton O_3 (ozone - USEC), £12,205 per metric ton NO_2 (nitrogen dioxide - UKSDC), £1,633 per metric ton SO_2 (sulphur dioxide - UKSDC), £33,714-£66,264 per metric ton PM_{10} (Particulate matter less than 10 microns and greater than 2.5 microns - UKSDC), £7,609 per metric ton $PM_{2.5}$ (particulate matter less than 2.5 microns – USEC).

Stormwater alleviation value: The amount of water held in the tree canopy and re-evaporated after the rainfall event (avoided runoff) and not entering the water treatment system. The value is based on the 2015/16 household standard volumetric rate per cubic metre charged by Welsh Water for foul only and does not include full service; a rate of £1.3238 per m^3.

Carbon storage and carbon sequestration values: Calculated from a baseline year of 2015 and the respective 2015 DECC value of £62 per metric ton.

Building Energy saving value is calculated based on the prices of £126.7 per MWH and £ 11.15 per MBTU.

Replacement Cost: The value of the trees based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree), the value is determined within i-Tree Eco according to the CTLA (Council of Tree and Landscape Appraisers) method.

Amenity Value: Calculated using the Capital Asset Valuation for Amenity Trees (CAVAT) method.

Comparisons to Other UK i-Tree Eco Studies

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

- Torbay (Rogers et al. 2012)
- Edinburgh City (Hutchings et al. 2012)
- Wrexham CB (Rumble et al. 2014)
- Glasgow City (Rumble et al. 2015)
- Bridgend CB (Doick et al. 2015)

Results and Discussion

This chapter presents the results of the i-Tree Eco survey of the Tawe catchment, as a single area of study. A breakdown of elements of these results is presented in Appendix II - Swansea, Appendix III – Neath Port Talbot and Appendix IV – Powys, where the current i-Tree Eco model is able to perform such calculations.

Sample Area

Based on the sample plots, 24(±2)% of the ground cover in the Tawe catchment is suitable for planting with additional trees. Tree canopy cover is 16(±2)%, which is highly comparable to the Welsh average of 16.8% (Fryer 2014), similar to that found in the Edinburgh i-Tree Eco study (17%) and much higher than the average in English towns (8%, Britt & Johnston, 2008).

The total size of the Tawe catchment urban forest is 1,119 ha. This is twice the area of Fairwood, Pengwern and Welshmoor Commons which covers 625 ha (Figure 4). Shrub cover including shrubs below the tree canopy is 15(±1)%, the same as found in the Edinburgh i-Tree Eco study, and higher than that found in either the Wrexham CB (11%) and Bridgend CB (9%) i-Tree Eco studies.

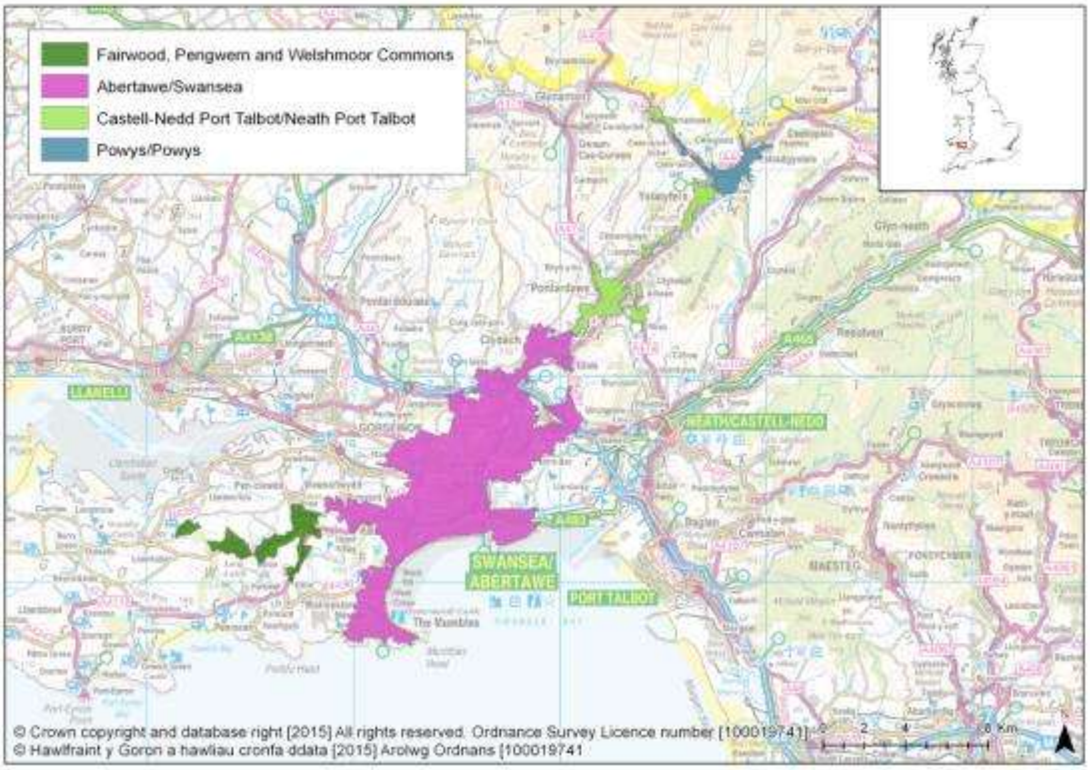

Figure 4. The urban forest of the Tawe catchment covers a size of 1,119 ha. By comparison, Fairwood, Pengwern and Welshmoor Commons have a total area of 625 ha.

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

	Location					
	Tawe catchment	Bridgend CB	Glasgow	Edinburgh	Torbay	Wrexham CB
Study area size (ha)	6,995	4,440	17,643	11,468	6,375	3,833
Sample density (one plot per […] ha)	28	22	88	57	26	19
Canopy cover (ha)	1,119	533	2,647	1,950	752	652
% Forest cover	16	12	15	17	12	17
Average number of trees per ha	76	99	112	56	105[1]	95

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

Box 2. Tree canopy cover in the Tawe catchment

The Tawe catchment has a canopy cover of 16%. This is similar to the national average across Wales of 17%, although does not rank highly internationally. For example, the city of Toronto has a tree cover of 20%, New York of 21% and Barcelona has 25% tree cover. Comparison with cities at the global scale is interesting because it provides a form of benchmark; however, they should be made with caution as comparisons alone to do not provide explanations for the differences in forest structure and function, such as landscape design history. Currently, there aren't any national or internationally recognised targets for tree canopy cover in urban areas. However, 18.6% is a conservatively calculated mean cover for 26 larger European cities (Konijnendijk, 2001) and increasing canopy cover in the Tawe catchment will increase the amount and value of ecosystem services provided to society by trees. Increasing canopy cover through the planting and quality management of long-lived large canopy trees is likely to deliver a wider range of benefits than increasing canopy cover through planting new small canopied trees - as demonstrated throughout the remainder of this report.

Ground Cover

Ground cover in the Tawe catchment study area consisted of 53% permeable materials, such as grass and soil; the remainder consisted of non-permeable surfaces such as tar and cement (Figure 5). Permeable surfaces can reduce problems associated with flash flooding, such as travel disruption and damage to infrastructure, and reduce loads on sewer systems. Swansea Valley is recognised as an area at risk of flooding (www.swansea.gov.uk/lowerswanseavalleyflood) and had a £7 million flood management scheme completed in 2014. At 53%, the percentage of permeable cover in the Tawe catchment is the same as that reported in the Glasgow city and Wrexham CB i-Tree Eco studies (53%) and similar to that in the Bridgend CB i-Tree Eco study (49%).

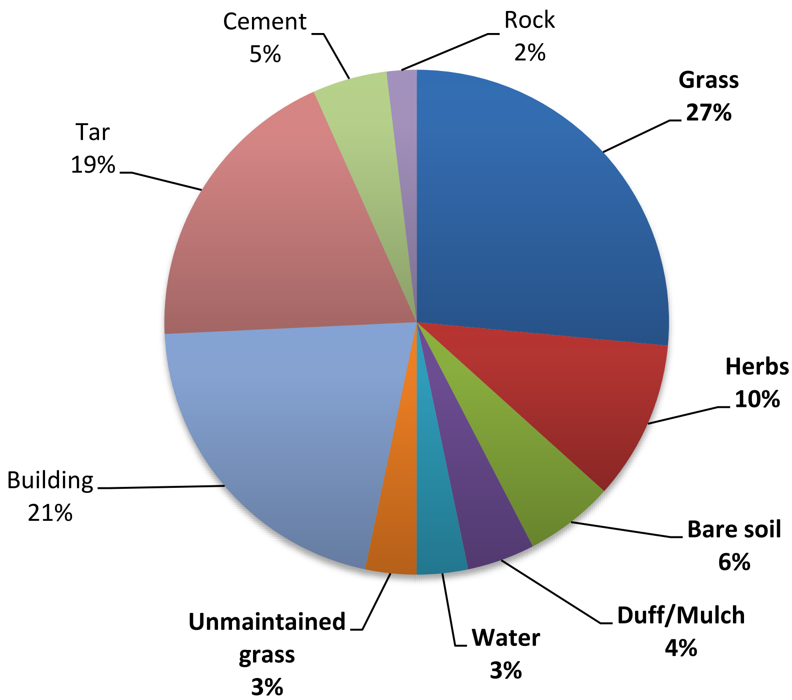

Figure 5. Types of ground cover encountered in the Tawe catchment study. Bold labels denote permeable surfaces, the remainder are non-permeable.

Urban Forest Structure

Species Composition

The urban forest of the Tawe catchment has an estimated tree population of 530,000. This is a density of 76 trees per hectare, which is lower than in the Bridgend CB (99 trees per hectare) and Wrexham CB (95 trees per hectare) i-Tree Eco studies, while higher than the Welsh average of 45 trees per hectare (Fryer 2014) and the English average of 58 trees per hectare (Britt & Johnston 2008).

The three most common species are common alder, goat willow and downy birch; and the ten most common tree species account for 62% of the population (Figure 6).

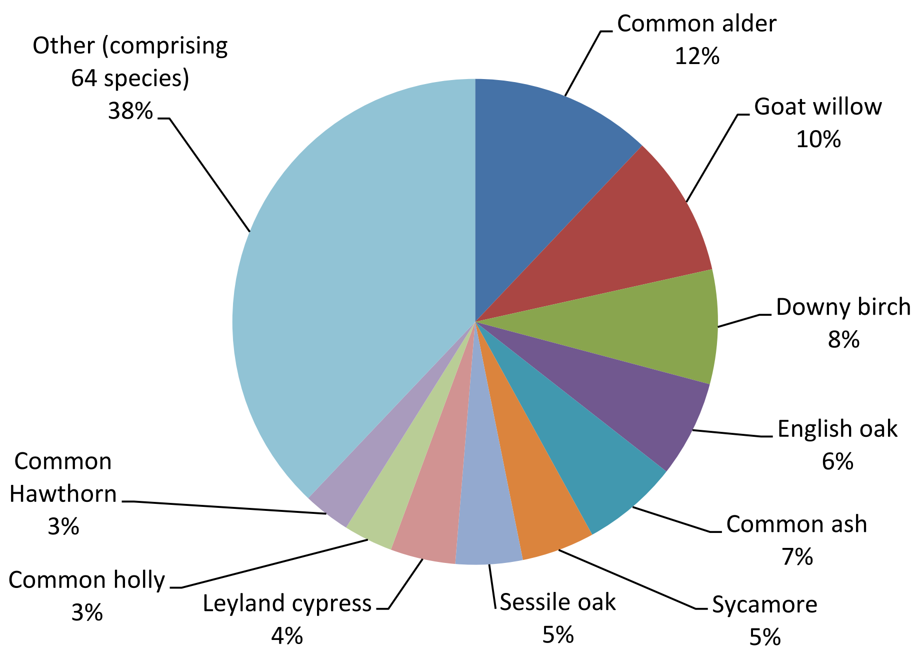

Figure 6. Breakdown of tree species in the Tawe catchment survey.

Where trees were present, they most commonly occurred in vacant land (26%; definitions for each land use type are included in Table 16, Appendix I), residential land (25%) and in park land (22%; Figure 7). Overall, the majority of trees are found in private ownership (62%)[5].

[5] 'Private' includes the land-uses: residential, multi-residential, golf-courses, institutional, commercial, agriculture.
'Public' refers to the land-uses: park, transport, cemetery, vacant

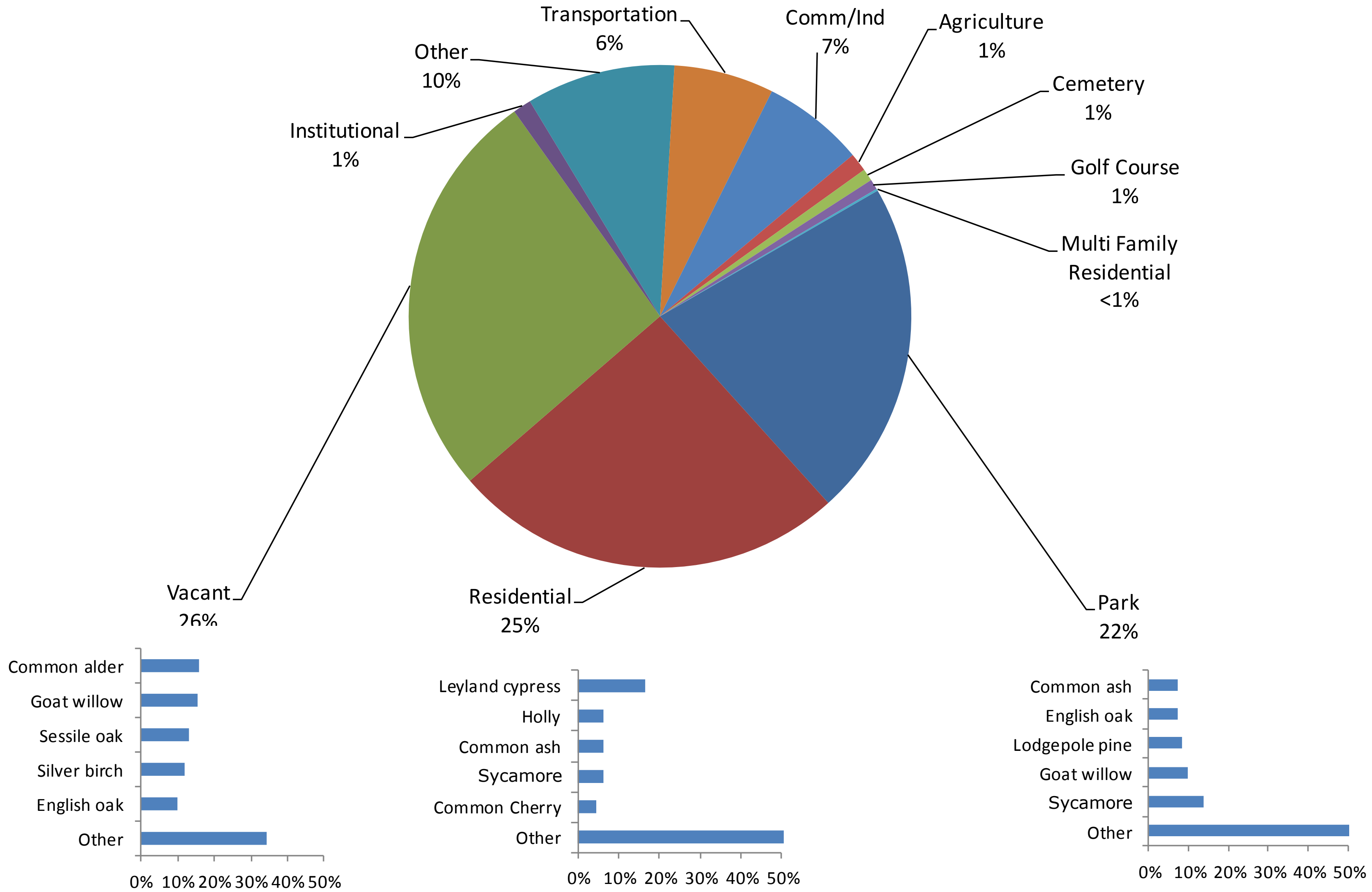

Figure 7. Land use types on which trees were present. Land use types where no trees were found are omitted. Bar charts of the top 5 tree species in each of the top three land-use types also presented.

Species Composition by Origin

The origin of tree species also impacts their ability to resist pests and diseases. New pests and diseases, such as Chalara ash dieback, are emerging. Additionally, stresses such as prolonged exposure to drought and flood are projected to increase due to climate change (UKCP09 2009). These factors are leading some council's to consider the use of exotic species. Exotic species tend to have fewer pests associated with them due to being removed from the home range of their specialist predators and diseases (Connor et al. 1980). Trees from warmer climates may also be able to withstand the effects of climate change better (RHS 2014). However, there is an on-going debate about whether these benefits outweigh the costs of planting exotics (Johnston et al. 2011). Exotic species can disrupt native ecosystems by changing the available niches for wildlife to fill (Townsend et al. 2008). They also support fewer native animals (Kennedy & Southwood 1984) and can become invasive (Mitchell & Power 2003). A balance of native and non-native species may provide the most resilient solution. Of those trees identified to species level, 38 % are native to the UK and 62 % are non-native[6].

Species Diversity

A total of 88 tree and shrub species were encountered during the study (for a full list see Appendix V - Species Importance List). This is more than identified in the Wrexham CB (54 species) and Bridgend CB (60 species) and i-Tree Eco studies.

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 (Common alder, Goat willow and Downy birch). No genus exceeded 20% frequency and no family exceeded 30%. Table 4 outlines the top three species, genus and family frequencies in the Tawe catchment survey.

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

	1st		2nd		3rd	
Species	**Common alder**	**16.9 %**	**Goat willow**	**13.2 %**	**Downy birch**	**10.7 %**
Genus	Alnus	13.8 %	Salix	11.5%	Quercus	11.4 %
Family	Betulaceae	25.2 %	Salicaceae	14.4%	Fagaceae	12.2 %

Bold entries denote groups exceeding the guidelines outlined by Santamour (1990) of no. species exceeding 10%, no. genus 20% and no. family 30%

6 17% were identified to genus level only so could not be assigned a native, naturalised or non-native status

Box 3. Tree species diversity

The greatest diversity of trees in the Tawe catchment study was located on residential, park and vacant land. Given that commercial and institutional land, cemeteries and multi-residential land are typically highly managed, species diversity could be increased through considered species selection, underpinned by education or policy. Selecting to broaden the variety of tree species could increase the diversity offer of the Tawe catchment's urban forest, and a concomitant increase in resilience in light of a changing climate, increased public amenity value and a broader support to biodiversity.

Diversity Index

The diversity of tree species, i.e. the number of different species present in a population and their numbers, is important because diverse populations are more resistant to pests and diseases (Johnston et al. 2011). The diversity of populations can be calculated using the Shannon-Wiener index. This is a measure of the number of different species, taking into account whether the population is dominated by certain species. The mean diversity score of the Tawe catchment urban forest is 3.0 according to this index. This is marginally lower than Bridgend (3.6) but similar to Wrexham (3.1). The highest diversity of trees were found in residential areas (3.0) and parks (2.6) (Figure 8).

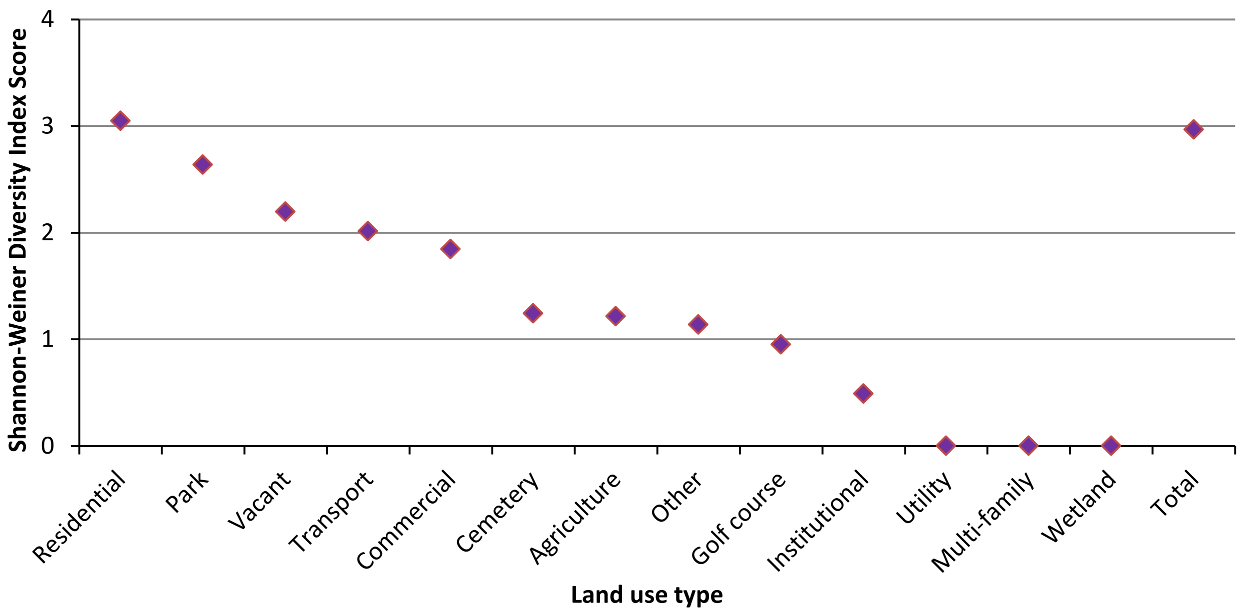

Figure 8. Shannon wiener diversity index scores for trees on different land use types in the Tawe catchment.

Size Class Distribution

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

It is estimated that trees with a DBH <20 cm constitute 56% of the total tree population in the Tawe catchment (Figure 9a). The number of trees in each DBH class then declines successively, where trees with a DBH >60 cm make up just under 4% of the tree population. Analysis of only large stature trees[7] shows that 60 cm+ diameter trees account for only 4% of the tree population (Figure 9b), which is much lower than the 10% value suggested by Richards (1983) as necessary to ensure a healthy stock of street tree. The proportion of trees with diameters between 40 and 60 cm is also low, suggesting that the population of large stature trees is comprised of a very high proportion of young immature trees and that there is a shortage of trees that will mature into large diameter trees in the future. Analysis of only the small stature trees[8] is shown in Figure 9(c). These trees will not attain large stature and therefore there are high numbers of these trees in the lowest DBH class; however, approximately one quarter is in the 20-40 cm DBH class, suggesting a good population of mature small stature trees in the Tawe catchment.

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

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

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

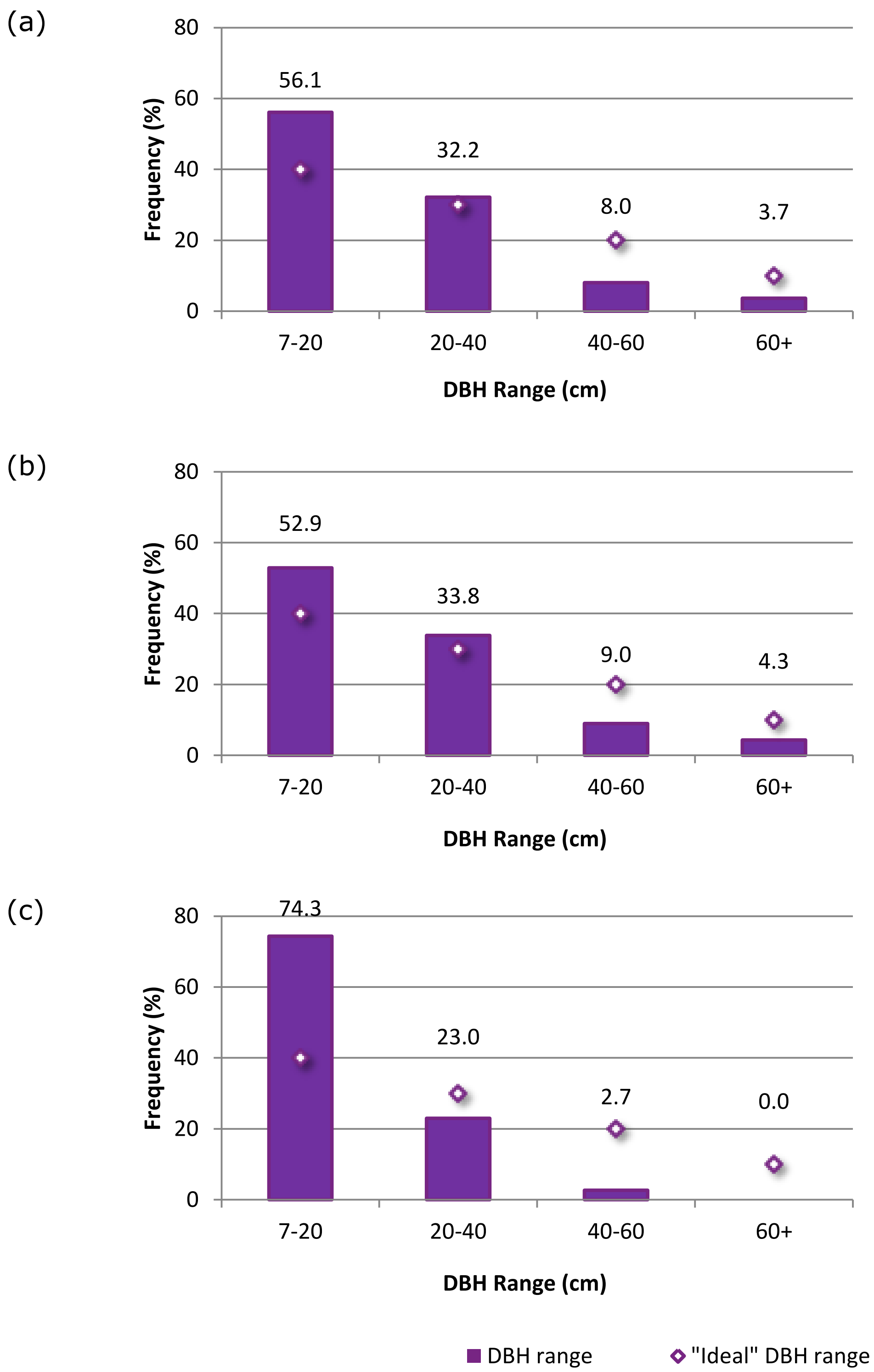

Figure 9. DBH ranges of trees (a) encountered in the Tawe catchment survey , (b) encountered, with small stature trees removed from the analysis and (c) encountered in the Tawe catchment survey, with large stature trees removed from the analysis (with data values shown for clarity). Diamonds represent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

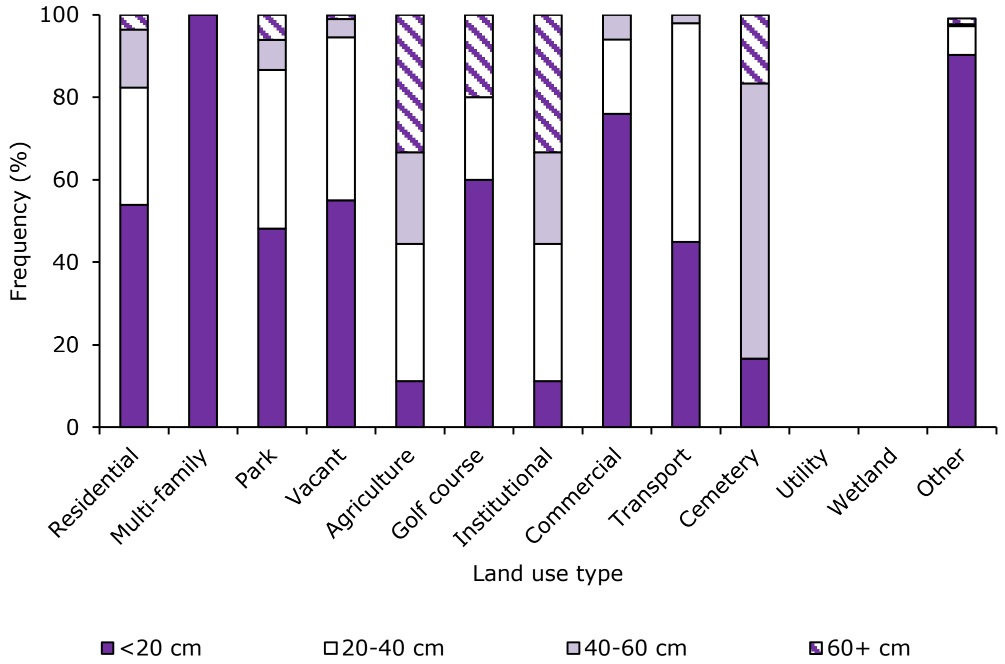

Figure 10. Proportion of diameter size classes per land use type. A missing value denotes land use types where no trees were found.

Small trees (<20 cm DBH) were highest in proportion on multi-family land, 'other' and commercial land (Figure 10). Large trees (>60 cm DBH) were highest in proportion on agricultural land, institutional land and golf courses (Figure 10).

Box 4. Diversity in tree size

The proportion of trees of different size across the Tawe catchment broadly reflects the findings of previous i-Tree Eco studies in the UK, for example with large trees (60 cm+ DBH) mostly found on land uses unlikely to have changed in recent history. The relatively low abundance of large trees on vacant land and high abundance on cemetery land, however, bucks this trend and the generally low frequency of 40-60 cm DBH trees means there are low numbers that will grow into large stature trees in the short-to-medium term. The land use with the largest proportion of 20-40 cm DBH trees is 'transport'. Given highway maintenance practices to limit the maturing of large stature trees along carriageways, urban planners in the Tawe catchment should seek to conserve and expand the resource of this size tree class across other land-use types. Overall, there is a high proportion of small trees (7-20 cm DBH) – careful management of these trees throughout their maturation will help to address the generally low levels of medium and large stature trees and improve size diversity across the Tawe catchment's urban forest; a programme of planting would also ensure an on-going presence of small trees.

Tree Condition

The condition of the Tawe catchment trees was good, with 45% of trees in excellent condition (no dieback) and 21% of trees in good condition. A further 21% of trees had more than 25% dieback (poor to dead rating) (Figure 11). Condition is a useful measure of the potential prevalence of pests or diseases and the need for further enquiry, for example targeted at specific species where obvious trends are observed. While a proportion of dead trees is important because of their contribution to biodiversity, tree condition is notably worse across the Tawe catchment than in the Wrexham CB or Bridgend CB i-Tree Eco studies that reported 13% and 6% of trees, respectively, with more than 25% dieback.

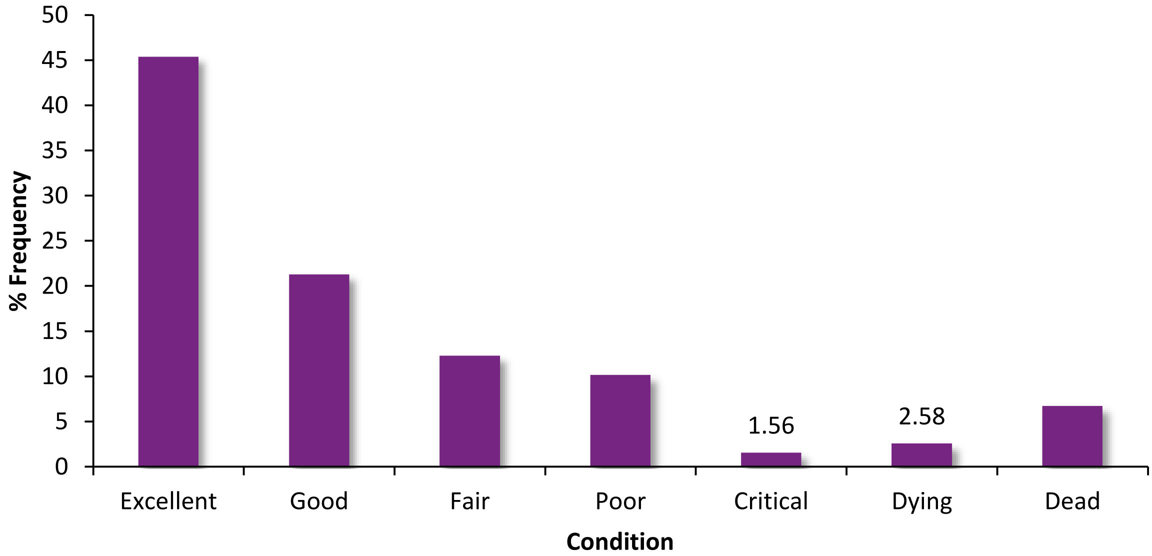

Figure 11. Condition of trees encountered in the Tawe catchment.

Leaf Area and 'Importance Value'

The healthy leaf surface area of trees is an indicator of many of the benefits that trees can provide, including the removal of pollutants from the atmosphere (Nowak et al. 2006) and shade provision. The total leaf area provided by the Tawe catchment's trees is 48 km^2; this is more than twice the size of Swansea City (20.4 km^2) and only a little short of the size of Cardiff City (50.2 km^2; based on the Ordnance Survey's 1:625,000 scale GB BaseData map). Sycamore, Ash and English oak provide the most leaf surface area (13%, 9% and 9% respectively) (Figure 12). A list of the importance values for all 88 species encountered during the study is presented in Appendix V - Species Importance List.

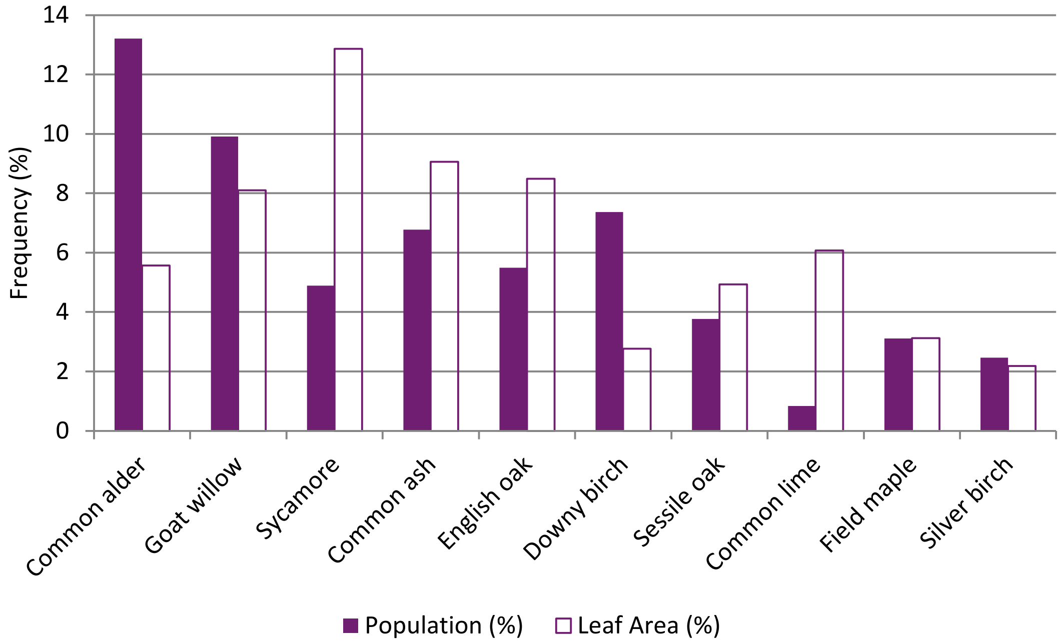

Figure 12. The top ten trees encountered in the Tawe catchment study with respect to the population size (%) and Leaf Area (%).

Importance value is calculated in i-Tree Eco as the sum of leaf-area and population size as an indication of which tree species within an urban forest are contributing most to ecosystem service provision. Trees with dense canopies and/or large leaves tend to rank highly due to their relatively large contribution to the urban forest's total leaf surface area. The top three tree species in the Tawe catchment study, by importance value, were those which appeared in greater numbers such as alder and willow, and those with large leaves, such as sycamore (Table 5). Thus, the most prevalent species were not always the most important (Figure 12, Table 5).

Table 5. Top ten tree species encountered in the Tawe catchment study, by Importance Value.

Species	IV
Common alder	18.8
Goat willow	18.0
Sycamore	17.8
Common ash	15.8
English oak	14.0
Downy birch	10.1
Sessile oak	8.7
Common lime	6.9
Field maple	6.2
Silver birch	4.6

Box 5.Tree 'Importance Value'

Importance value is calculated in i-Tree as the sum of leaf area and population size, thus the most common trees and those which have large leaves tend to rank higher in importance as they provide relatively more ecosystem services. Two small stature trees - common alder and goat willow are the two most important species in this regard in the Tawe catchment urban forest; a consequence of their relative contributions to the total tree population. This is relatively uncommon with respect to other UK i-Tree Eco studies, wherein large stature large and high leaf area trees such as sycamore and oak tend to have the highest importance value. Maintaining a healthy population of mature large stature trees, such as oaks and limes, as well as evergreens is important for achieving a high level of ecosystem service delivery via a species and structurally diverse urban forest. Sycamore, common ash and English oak are the species with the third, fourth and fifth highest importance value in this study. Care of these together with supplementary planting of more limes (also in the top ten in this study) would be an effective means to increase ecosystem service delivery across the Tawe catchment.

Replacement Cost and Amenity Value

CTLA valuation

The urban forest of the Tawe catchment has an estimated **replacement value of £234 million** according to the CTLA (Council of Tree and Landscaper Appraisers) valuation method incorporated into i-Tree Eco. This is the cost of replacing the urban forest of the Tawe catchment should it be lost; this valuation method does not take into account the health or amenity value of trees.

CAVAT valuation

The urban forest of the Tawe catchment an estimated **public amenity asset value of £816 million** according to CAVAT (Capital Asset Value for Amenity Trees) valuation, taking into account the health of trees and their public amenity value. The English oak in the Tawe catchment have the highest overall value (Figure 13, Table 6), representing 6.4% of the total public amenity value of all of trees in the Tawe catchment's urban forest. The single most valuable tree encountered in the study was a Western balsam poplar, estimated to have an asset value of £57,500.

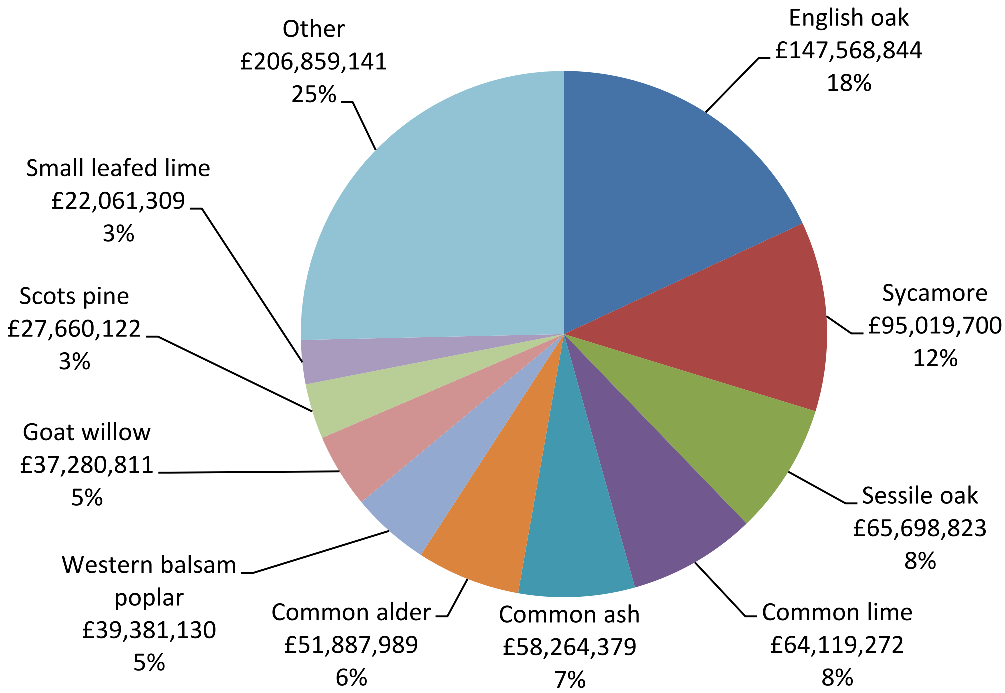

Figure 13. Ranking of the top-ten tree species according to their CAVAT valuation.

Table 6. CAVAT values for the top ten trees by genus.

Genus	Number of species	Value of measured trees	Total value across the Tawe Catchment
Oak spp	4	£319,259	£218,540,228
Maple spp	6	£153,674	£105,193,232
Lime spp	2	£125,899	£86,180,581
Poplar spp	4	£89,623	£61,349,324
Ash spp	2	£85,295	£58,386,340
Alder spp	4	£82,995	£56,812,190
Willow spp	5	£67,062	£45,905,403
Pine spp	4	£53,053	£36,315,868
Birch spp	3	£47,770	£32,699,479
Cypress spp	1	£24,657	£16,878,482
Total	**88**	**£1,191,780**	**£815,801,519**

The land use type containing the highest CAVAT value of trees is parks, with over a third of the total value of trees within this land use type - estimated value of approximately £444,000. This equates to almost £304 million when extrapolated for the whole of the Tawe catchment. Multi-family residential land, agricultural land, golf courses and cemeteries, collectively, contained the lowest percentage of public amenity value trees in this study, <4% of the total value (Figure 14). Trees on these land-use types typically return a higher contribution to total public amenity. This result may be, on the one hand, a reflection of the relatively poor tree condition observed across the Tawe catchment (see Tree Condition for further details), and on the other hand, a reflection of the small percentage contribution of these land-uses to the tree population and the study overall.

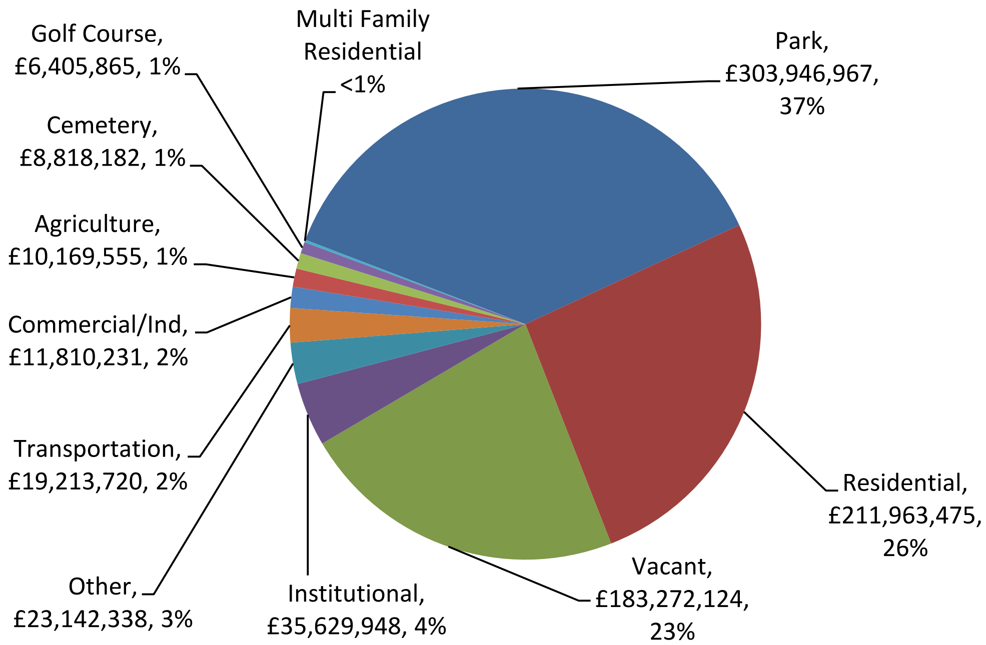

Figure 14. Percentage public amenity value held by trees in the Tawe catchment according to land use type.

Box 6. Amenity value trees

CAVAT is designed to underpin the management of trees as assets of the local authority and to give a monetary value to individual trees, such as may be required in subsidence claims. The valuation method involves five steps, starting with determining a basic value for the trees and then adjusting in the following four steps for the tree's i) location and accessibility by the general public, ii) vitality relative to that of a well-grown healthy tree of the same species , iii) amenity and suitability to the location, which may be either positive or negative, and finally iv) according to life expectancy. Trees that have high CAVAT values are thus those of large size that are highly visible to the public, which are healthy and are well suited to the location, both in terms of their ability to grow there as well as their specific contribution to the character of the place.

Across the Tawe catchment, agriculture and institutional land were the land use types with the greater percentage of large stature trees – however, with their intrinsically low accessibility to the general public these large trees did not lead to these land use types having the highest amenity value. Conserving maturing large stature trees in publically accessible places, as well as complementary planting that is mindful of suitability to a location, will help to ensure that the urban forest of the Tawe catchment has high public amenity into the future. Preference should be given to large stature trees where possible, and to the selection of species with special amenity such as bark colour or canopy architecture. Selection should always be guided by local policy and suitability to the soil and location.

Avoided surface water runoff

The infrastructure required to remove surface water in urban environments is costly and is out-dated in many of the towns and cities in Wales. This means that in large storm events or when water pipes fail surface water may not be removed quickly and damage to property can incur. Trees can ameliorate this problem by intercepting rainwater, retaining it on their leaves and absorbing some into their tissues for use in respiration. The roots of trees can also increase natural drainage and this is particularly important for stormwater amelioration where the surface around the trees is permeable allowing the water to infiltrate into the soil (although this is not calculated within i-Tree Eco). **The trees in the Tawe catchment intercept an estimated 252,200,000 litres of water per year**, equivalent to 120 times the volume of the 50 m swimming pool at the Wales National Pool, Swansea. Based on the standard local rate charged for sewerage[9], this would save £333,865 in sewerage charges across the Tawe catchment (Table 7).

[9] This value is based on the 2015/16 household standard volumetric rate per cubic metre charged by Welsh Water for foul only and does not include full service. This rate is stated as £1.3238 per m^3 (Welsh Water 2015)

Table 7. Avoided Runoff for Trees in the Tawe catchment.

Est. number of trees	535,458
Leaf area (km^2)	48
Avoided runoff (Litres / yr)	252,200,000
Avoided runoff value (£)[9]	333,865

i-Tree Eco reports the avoided surface water runoff provided by the various tree species of the urban forest of the Tawe catchment. Sycamore intercepts the most water, removing 32,340,000 litres of water per year, worth £42,812 in sewerage charges (Figure 15).

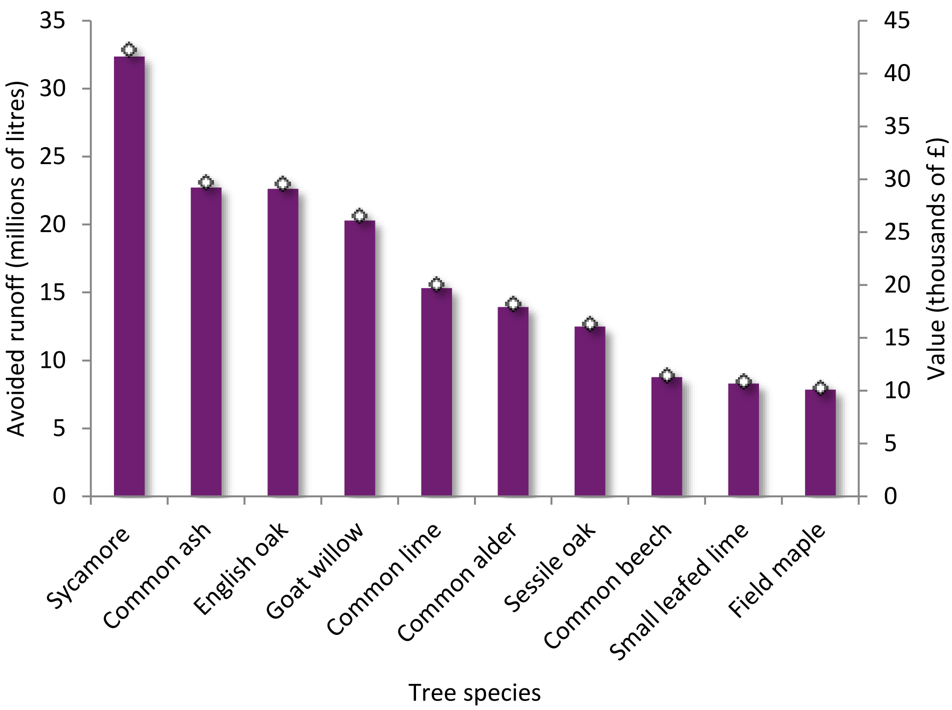

Figure 15. Avoided surface water runoff provided by urban trees in the Tawe catchment (columns) and their associated value in avoided sewer costs (diamonds).

Box 7. Rainfall interception by urban trees

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

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

Air Pollution Removal

Air pollution leads to a decline in human health, a reduction in the quality of ecosystems and it can damage buildings through the formation of acid rain (Table 8).

Trees and shrubs can mitigate the impacts of air pollution by directly reducing airborne pollutants as well as reducing local temperatures. Trees can absorb pollutants through their stomata, or simply intercept pollutants that are retained on the plant surface (Nowak et al. 2006). This leads to year-long benefits, with bark continuing to intercept pollutants throughout winter (Nowak et al. 2006). Plants also reduce local temperatures by providing shade and by transpiring (Bolund and Hunhammar, 1999), reducing the rate at which air pollutants are formed, particularly ozone (O_3; Jacob & Winner 2009). However, trees can also contribute to ozone production by emitting volatile organic compounds (VOC's) that react with pollutants (Lee et al. 2006). i-Tree Eco reports biogenic emissions of Monoterpene and Isoprene, the most important naturally emitted VOC's (Stewart et al. 2002).

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

Table 8. Urban pollutants, their health effects and sources.

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

Source: www.air-quality.org.uk

It is estimated that **136.2 tonnes of airborne pollutants per year are removed by the urban forest of the Tawe catchment**, including NO_2, O_3, SO_2, CO, PM_{10} and $PM_{2.5}$. O_3 and NO_2 were the pollutants removed in the highest volume by trees. This demonstrates that although trees can increase ozone levels by producing VOC's, they remove far more that they produce. In addition, as ozone production increases with temperature, 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 9) because of the uncertainty associated with the value of removing some airborne pollutants. In addition, the value of PM_{10}'s can vary depending on their emission source.

Using the UK system, which only includes three pollutants, **£715,473[10] worth of pollutants are removed from the atmosphere** (Table 9; Figure 16). Using the US valuation system, £1.4 million worth of pollutants are removed by urban trees in the Tawe catchment (Table 9).

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

Table 9. Amount of each pollutant removed by the Tawe catchment's 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	0.6	1,619	971	*n/a*	
NO_2	22.8	11,397	259,852	12,205 (NO_x)	278,567
O_3	83.0	11,397	945,951	*n/a*	
PM_{10}	12.7	7,609	96,718	33,713 ($PM_{10,}$ domestic)	428,526
				66,264 ($PM_{10,}$ transport urban medium)	*842,282*
$PM_{2.5}$	11.9	7,609	90,547	*n/a*	
SO_2	5.1	2,790	14,229	1,633 (SO_x)	8,381
Total	**136.2**		**1,408,827**		**715,473**

n/a = not available

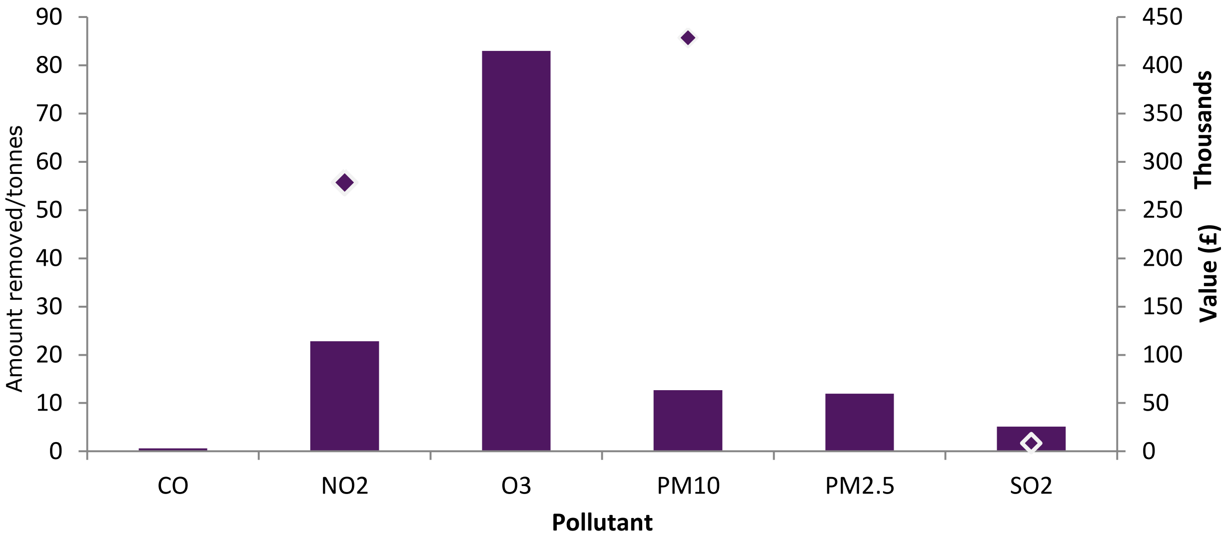

Figure 16. Mean quantity of pollutants removed by urban trees in the Tawe catchment (columns) and the associated value (diamonds) as valued using the UK SDC system.
PM_{10} excludes $PM_{2.5}$ (i.e. particulate matter 2.5-10 microns, only).

The volume of airborne pollutants varied over the year, with a seasonal pattern evident in the removal of ozone, which was removed in higher volumes during spring and summer (Figure 17). This is because ozone is a product of the combination of NO_x, which was also removed in greater volumes in summer, and VOC's. The production of ozone is also more prevalent in warm temperatures (Sillman & Samson 1995). In addition, this creates a diurnal pattern, with ozone levels higher during the day than at night (Nowak, 2000).

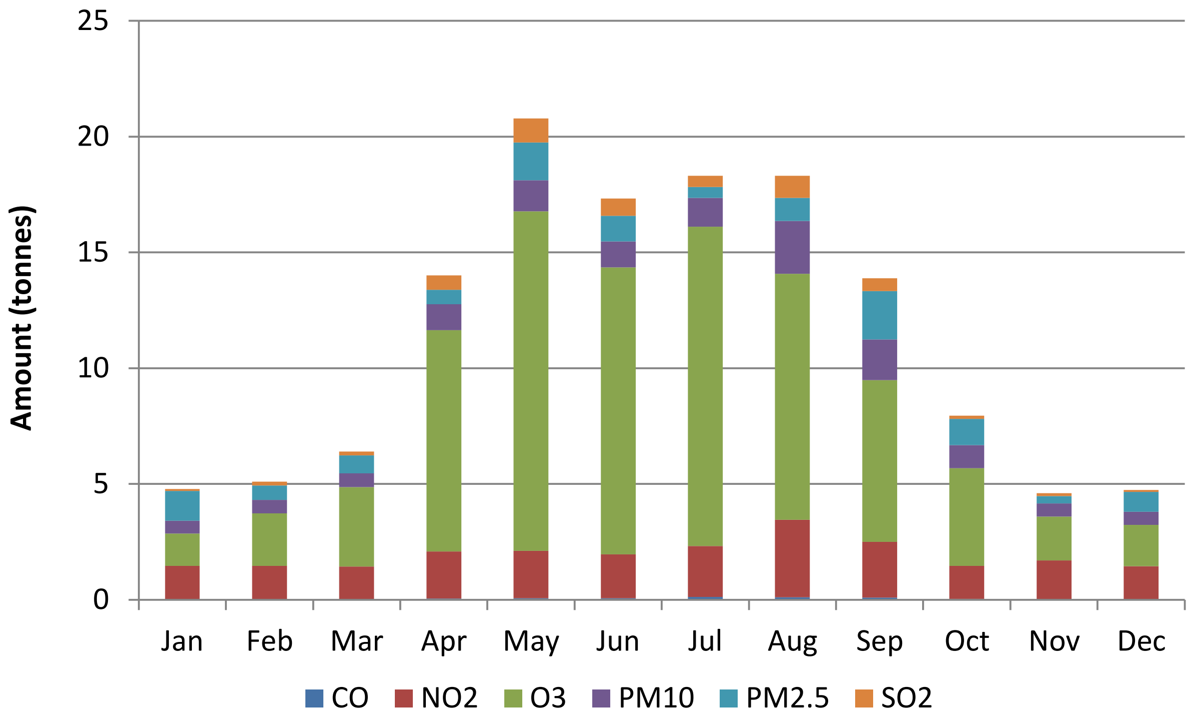

Figure 17. Amount of pollutants removed by the Tawe catchment's urban trees on a monthly basis.

Box 8. Air pollution removal by urban trees

Trees can intercept airborne pollution. Some is retained on plant surfaces – leaves and bark, and some is absorbed through the stomata. By cooling local air temperatures, plants also reduce the rate at which air pollutants are formed, particularly ozone. Of the trees present in the Tawe catchment urban forest alder, ash and birch remove the most pollutants. And while sycamore, oaks and willows can detrimentally affect the air quality through release of VOCs that can contribute to the formation of new pollutants, i-Tree Eco calculates that the trees of the Tawe catchment have a net positive impact on air quality – removing an estimated 136 tonnes of airborne pollutants per year.

Some recent scientific studies have shown that trees can worsen urban air quality by trapping pollutants at street level. Closer scrutiny reveals that whether trees trap air or help divert it away depends on their positioning and avoiding canopy closure over a street. It is therefore important to consider a tree's canopy architecture as well as street shape and orientation to the prevailing wind when planting street trees.

Carbon Storage

It is estimated that **Tawe catchment's trees store a total of 102,000 tonnes of carbon in their wood**, with English oak storing the greatest amount (Figure 18). This is equivalent to 130% of the annual carbon emissions produced by all the households in the Tawe catchment[11,12]. Alternatively, this is equivalent to the annual CO_2 emissions of 185,500 cars[13], or almost twice (171%) the total estimated annual CO_2 emissions produced by all the cars owned in Swansea[12].

Similarly to leaf area, carbon storage depends not only on the number of trees present, but also their characteristics. In this case, the mass of a tree is important, as larger trees store more carbon in their tissues. English oak, for example, makes up 6% of the Tawe catchment's tree population, but is responsible for storing 20% of the total carbon stored in trees (the largest difference); common alder on the other hand, stores only 8% of carbon but makes up 12% of the tree population, the highest % frequency.

The carbon in trees can be valued within the framework of the UK government's carbon valuation method (DECC 2014). This is based on the cost of the fines that would be imposed if the UK does not meet carbon reduction targets. These values are split into two types, traded and non-traded. Traded values are only appropriate for industries covered by the European Union Emissions Trading Scheme. Tree stocks do not fall within this category so non-traded values are used instead. Within non-traded values, there are three pricing scenarios: low, central and high. These 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 carbon in the current tree stock is worth £23.1 million.** In 2050, this stock of carbon will be worth £50.1 million – this value assumes no change in the structure of the forest in terms of species assemblage, tree size or tree population size, and simply reflects the increased valued of non-traded carbon year-on-year to 2050. Appendix VI. Non-traded values for carbon stored in the Tawe catchment's trees in all three valuation scenarios., outlines stored carbon value from now until 2050 for all three pricing scenarios, again values do not take into account any changes that might occur to the urban forest of the Tawe catchment.

[11] Based on an average UK household emission of 5 tonnes of CO_2 per year in 2009 (Palmer & Cooper 2011)
[12] Estimate based on the number of households estimated by Swansea & NPT councils & UK census data (local housing market assessment March 2009)
[13] Based on average emissions of 157g/CO_2 per km (cars registered after 2001, Department for Transport 2014), with the average UK car travelling 13,197 km per year (Department for Transport 2013)
[12]Based on car on 449.4 registered cars per 1,000 population (ONS 2014)

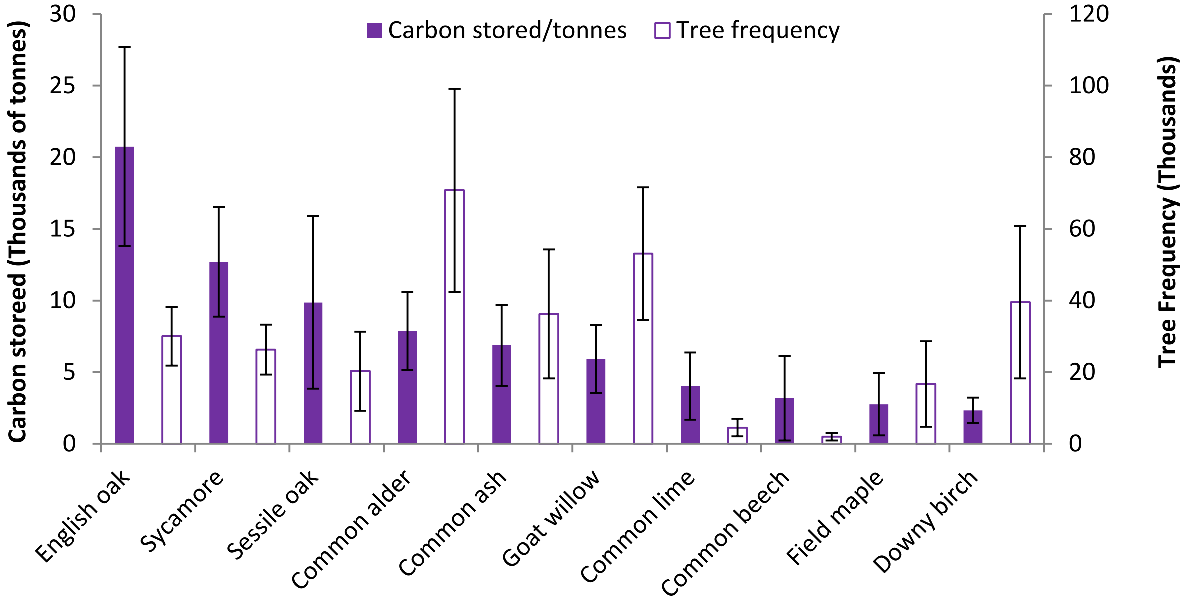

Figure 18. Amount of carbon stored in the Tawe catchment urban forest and the frequency of each species. Only the ten trees with the highest storage rates are displayed. Error bars denote standard error of the mean (SEM).

Carbon Sequestration

The gross amount of carbon sequestered by the urban forest in the Tawe catchment each year is estimated at 3,700 tonnes. Taking into account the number of dead trees (net storage), which release carbon into the atmosphere, **the Tawe catchment urban forest sequesters 3,000 tonnes of carbon per year** (0.5 t/ha); this **amount of carbon is estimated to be worth £671,000**. The net sequestration rate is equivalent to the annual emissions from 5,400 automobiles (7.6% of the number of cars in the Tawe catchment), or 2,200 family homes (3.8% of the households in the Tawe catchment).

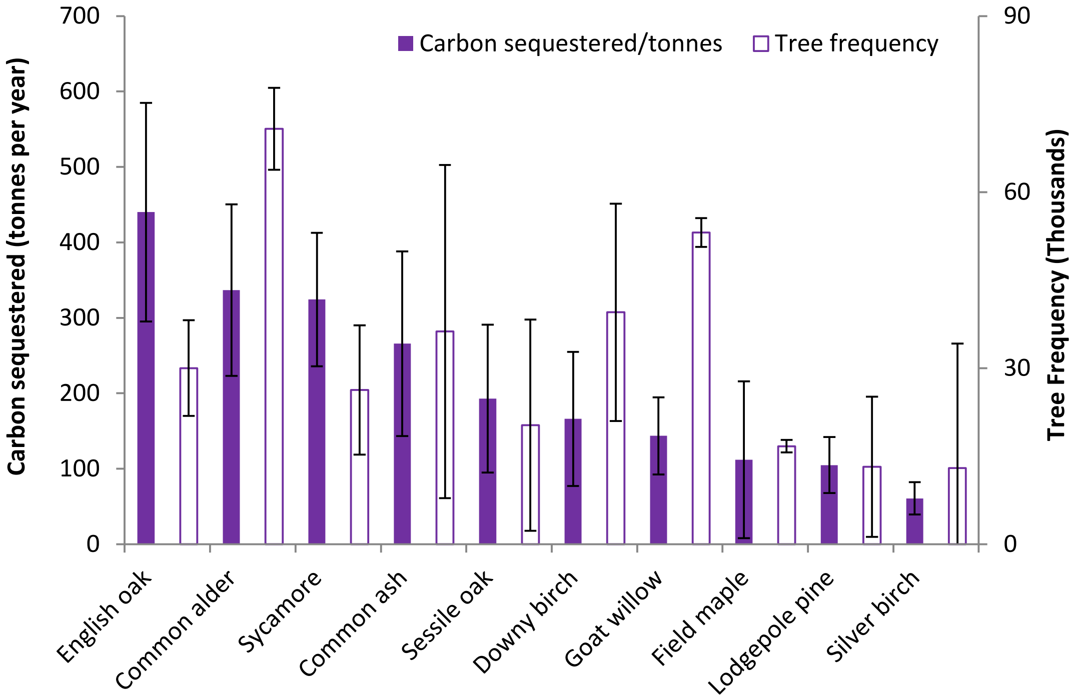

Figure 19. Carbon sequestered per year by the ten trees with highest rates, along with their frequency. Error bars denote standard error of the mean (SEM).

Box 9. Carbon storage and annual sequestration

The urban forest is an important repository for carbon, both with respect to the total amount of carbon stored as well as the annual sequestration rate. By absorbing carbon dioxide from the atmosphere trees help to combat a key driver of our changing climate.

This i-Tree Eco study shows that for the urban forest of the Tawe catchment, the large stature trees such as sycamore, oak, lime and beech store a large quantity of carbon relative to their abundance. Common alder also contribute substantially to the carbon storage by virtue of their high abundance. While the growth rate of trees in the urban environment is still subject to much research, oak, common alder and sycamore feature as the main contributors to the annual sequestration of carbon by the urban forest of the Tawe catchment.

Future planting within the Tawe catchment's urban forest should feature large stature trees because of their capacity to store large quantities of carbon over the long term, as well as quick growing and pioneer species, which will have a positive impact on carbon storage in the short-term.

Habitat Provision

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

Pollinating insects provide ecosystem services by pollinating food crops, but they are under threat from pressures including land-use intensification and climate change (Vanbergen & The Insect Pollinators Initiative 2013). Providing food sources could help. The Tawe catchment trees and shrubs are contributing to this food source, with thirty four of the genus' found in the Tawe catchment survey supporting pollinating insects (RHS 2012) (Table 10).

Many insect herbivores are supported by trees and shrubs. Some specialise on just a few tree species, whilst others are generalists that benefit from multiple tree and shrub species. Of the species found in the Tawe catchment survey, willow and oaks support the most varied insect herbivore species (Figure 20). Beetles, although supported by these species are better supported by Scots pine (Table 11), highlighting that though some species have fewer insects associated with them, they are extremely important for certain groups.

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

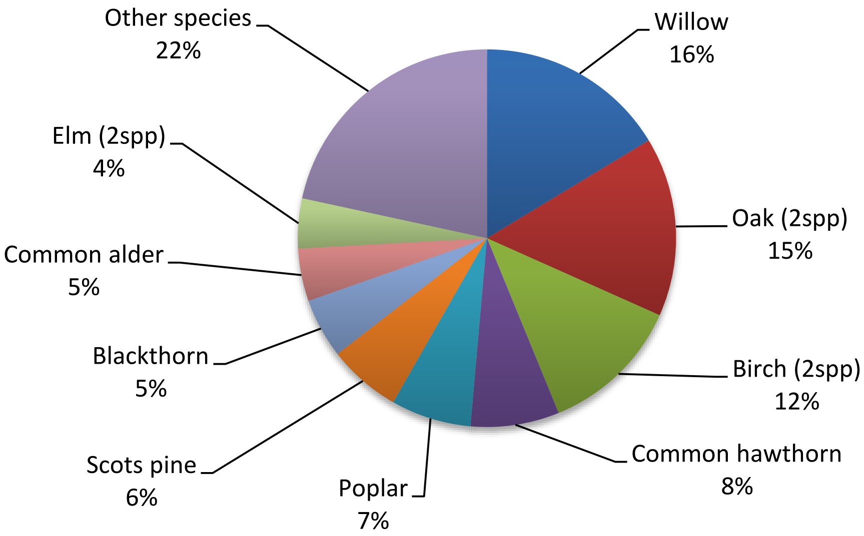

Figure 20. Relative importance of trees found in the Tawe catchment survey[14] for supporting insects. Where multiple tree species are denoted (in parentheses), insect species reflects the total associated with all hosts. Data from Southwood (1961) and Kennedy and Southwood (1984).

Box 10. Habitat provision by urban trees

Trees and shrubs provide valuable habitat and food for many animal and plant species, and while data availability on the role that each tree and shrub species has in supporting biodiversity found in the urban environment is far from comprehensive, over-arching principles such as native trees and shrubs associate with more faunal species than non-natives can be used to plan for a resilient urban forest that complements local biodiversity. Similarly, preferential planting of species identified in Tables 11a and 11b could be encouraged amongst private as well as local land owners. Local residents can be encouraged to play their part through education and awareness raising of publications by the RHS, RSPB and others on gardening for wildlife.

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

Table 10. Trees and shrubs encountered in the Tawe catchment that are beneficial to pollinators (RHS, 2012) presented by (a) genus and (b) species.

(a) Genus	Season	Tree/Shrub
Acer spp	Spring	Tree
Mahonia spp	Winter, Spring	Tree
Malus spp	Spring	Tree
Prunus spp	Spring	Tree
Pyrus spp	Spring	Tree
Salix spp	Spring	Tree
Sorbus spp	Summer	Tree

(b) Species	Season	Tree/ Shrub	Species	Season	Tree/ Shrub
Field maple	Spring	Tree	Common apple	Spring	Tree
Norway maple	Spring	Tree	Wild cherry	Spring	Tree
Sycamore	Spring	Tree	Common plum	Spring	Tree
Darwin's berberis	Spring	Shrub	Cherry laurel	Spring	Tree
Orange eye butterflybush	Summer	Shrub	Blackthorn	Spring	Shrub
Box, common	Spring	Shrub	Pyracantha spp	Spring	Shrub
Heather	Summer	Shrub	Rosmarinus officianlis	Summer	Shrub
Cornus spp	Summer	Shrub	Rubus spp	Summer	Shrub
Hawthorn	Summer	Tree	Goat willow	Spring	Tree
Fuchsia spp	Autumn	Shrub	Sedum spp	Spring	Shrub
Holly, common	Summer, Spring	Tree	Whitebeam	Summer	Tree
Ilex spp	Summer, Spring	Shrub	Rowan, common	Summer	Tree
Kalmia spp	Summer	Shrub	Small-leafed lime	Summer	Tree
Laurel bay	Summer	Tree	Common lime	Summer	Tree
Ligustrum spp	Summer	Shrub	Viburnum spp	Summer	Shrub

Table 11. Numbers of insect species supported by tree species (a) encountered in the Tawe catchment survey and (b) for other commonly found urban tree species which data is available#. Brightest green boxes denote tree species supporting the most insects and red denote the lowest number. Middle values are represented by a gradient between the two.

(a) Species	Scientific names	Total	Beetles	Flies	True bugs	Wasps and sawflys	Moths and butterflies	Other
Willow (5 spp)	*Salix* (5 spp)	450	64	34	56	104	162	9
Oak (2 spp)	*Quercus petrea and robur*	423	67	7	43	70	189	9
Birch (2spp)	*Betula* (2 spp)	334	57	5	30	42	179	9
Common hawthorn	*Crataegus monogyna*	209	20	5	23	12	124	8
Poplar (4 spp)	*Populus* (4 spp)	189	32	14	34	29	69	3
Scots pine	*Pinus sylvestris*	172	87	2	10	11	41	6
Common alder	*Alnus glutinosa*	141	16	3	18	21	60	9
Elm (2 spp)	*Ulmus (2 spp)*	124	15	4	22	6	55	11
Crab apple	*Malus sylvestris*	118	9	4	12	2	71	2
Common hazel	*Corylus avellana*	106	18	7	3	8	48	6
Common Beech	*Fagus sylvatica*	98	34	6	7	2	41	4
Common ash	*Fraxinus excelsior*	68	1	9	7	7	25	9
Rowan	*Sorbus aucuparia*	58	8	3	6	6	33	2
Lime (2 spp)	*Tilia* (2spp)	57	3	5	7	2	25	8
Field maple	*Acer campestre*	51	2	5	10	2	24	6
Common hornbeam	*Carpinus betulus*	51	5	3	10	2	28	2
Sycamore	*Acer pseudoplatanus*	43	2	3	10	2	20	5
European larch	*Larix decidua*	38	6	1	6	5	16	1
Common holly	*Ilex aquifolium*	10	4	1	2	0	3	0
Horse chestnut	*Aesculus hippocastanum*	9	0	0	5	0	2	2
Yew	*Taxus baccata*	6	0	1	1	0	3	1

(b) Species	Scientific names	Total	Beetles	Flies	True bugs	Wasps and sawflys	Moths and butterflies	Other
Blackthorn	*Prunus spinosa*	153	13	2	25	7	91	11
Norway spruce	*Picea abies*	70	11	3	14	10	22	1
Juniper	*Juniperis communis*	32	2	5	1	1	15	2
Sweet chestnut	*Castanea sativa*	11	1	0	1	0	9	0
Spruce (spps)	*Abies spp*	8	0	0	5	0	3	0
Common walnut	*Juglans regia*	7	0	0	2	0	2	3
Holm Oak	*Quercus ilex*	5	0	0	1	0	4	0
False acacia	*Robinia pseudoacacia*	2	0	0	1	1	0	0

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

Risks of Pests and Disease

Pests and diseases are a serious threat to urban forests. Severe outbreaks have occurred within living memory, with Dutch Elm Disease killing approximately 30 million trees in the UK (Webber 2010). Climate change may exacerbate this problem, ameliorating the climate for some pests and diseases, making outbreaks more likely (Forestry Commission 2014). Assessing the risk pests and diseases pose to urban forests is, therefore, of paramount importance. A risk matrix was devised for determining the potential impact of a pest or disease should it become established in the urban tree population of the Tawe catchment on a single genus (Table 12) and for multiple species (Table 13).

Table 12. Risk matrix used for the probability of a pest or disease becoming prevalent in the Tawe catchment urban forest on a single genus.

Prevalence	% Population		
	0-5	6-10	>10
Not in UK			
Present in UK			
Present in S. Wales			

Table 13. Risk matrix used for the probability of a pest or disease becoming prevalent in the Tawe catchment urban forest on multiple species.

Prevalence	% Population		
	0-25	26-50	>50
Not in UK			
Present in UK			
Present in S. Wales			

With increased importation of wood and trees in addition to a climate that is becoming more vulnerable to many pests and diseases, ensuring urban forests are resilient is of paramount importance. The high prevalence of alder in the Tawe catchment, for example, means that the urban forest is particularly susceptible to threats such as *Phytophthora alni*. Protecting the urban forest as a whole against threats such as this can be helped by increasing the diversity of tree species across the Tawe catchment. Other threats not yet present in the UK, such as 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 14 gives an overview of the current and emerging pest and diseases that could affect the Tawe catchment's urban forest, with a focus on those pests and diseases that lead to the death of the tree or pose a significant human health risk; further details on individual pests and diseases are provided in Appendix VII – Pests and Diseases. The tables present the population of the urban forest of the Tawe catchment at risk from each pest and disease, the associated amenity value of these trees and the value of the carbon that they store. Subsequently, the tables highlight the relative impact of these pests and diseases and indicate the likely impact on canopy coverage and diversity of the urban forest should the pest or disease become established. The information contained in the tables can be used to inform programmes to monitor for the presence and spread of a pest or disease, and strategies to manage the risks that they pose.

Table 14. Risks of emerging pests and diseases

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in South Wales	Risk of spreading to South Wales	Population at risk (%)	CAVAT value of sampled trees (£)	Stored carbon value trees(£)
Acute oak decline	*Quercus robur, Q. petraea*	SE England and Midlands	Confirmed cases on the Welsh/English border	High – already present	**10.9**	311,556	6,830,948
Asian longhorn beetle	Many broadleaf species (see Appendix IV)	None (previous outbreaks contained)	None	Medium risk – climate may be suitable	**62.2**	595,930	11,277,244
Chalara dieback of ash	*Fraxinus excelsior, F. angustifolia*	Cases across the UK	9 confirmed cases in Wales	High - already present	**6.8**	85,295	1,541,769
Emerald ash borer	*F. excelsior, F. angustifolia*	None	None	Medium risk (imported wood)	**6.8**	85,295	1,541,769
Giant polypore	Primarily *Quercus* spp., *Fagus* spp., *Aesculus* spp., *Sorbus* spp. and *Prunus* spp	Common in urban areas	Common in urban areas	High – already present	**17.3**	364,354	8,686,665
Gypsy Moth	Primarily *Quercus sp.*, secondarily *Carpinus betulus, F. sylvatica, C. sativa, B. pendula* and *Populus sp.*	London, Aylesbury and Dorset	None	Medium risk – slow spreading	**22.7**	386,285	8,602,495
Oak processionary moth	*Quercus* spp.	Three sites in S England	None	Medium, small colonies are containable	**11.4**	319,259	7,068,363

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in South Wales	Risk of spreading to South Wales	Population at risk (%)	CAVAT value of sampled trees (£)	Stored carbon value trees(£)
Phytophthora ramorum	*Q. cerris, Q. rubra, Q. ilex, F. sylvatica, C. sativa, Larix decidua, L. x eurolepsis*	Many UK sites, particularly in S Wales and SW England	Many cases in S. Wales	High – already present	**0.3**	21,970	808,475
Phytophthora kernoviae	*F. sylvatica, Ilex aquifolium, Q. robur, Q. ilex*ǂ	Mainly SW England and Wales	Five locations in S. Wales	High – already present	**8.6**	248,716	5,486,813
Phytophthora alni	*Alnus* spp.	Riparian ecosystems in the UK	Heavy losses in parts of Wales	High – already present	**13.8**	82,995	1,940,460
Dothistroma (red band) needle blight	*Pinus nigra ssp. laricio, P. contorta var. latifolia, Pinus sylvestris*	Several UK sites	Found in 3 out of 4 forest districts in Wales	High – already present	**6.3**	53,053	891,080
Spruce bark beetle	*Picea* spp.	Mainly W England and Wales	Established in Wales	High – already present	**0.5**	7,114	406,589

ǂ Shrub and other tree species are also affected, some of which were found in Swansea: 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*

Energy Use by Buildings

i-Tree Eco models tree position, orientation and distance relative to buildings to determine the impact of the urban forest on the energy use by buildings, with respect to (winter) heating and air-conditioning (cooling) during the summer.

This model component is designed for US climate types, building types and efficiency characteristics, heating fuel types and mixes, energy production methods and emission factors. i-Tree Eco is capable of generating energy effect outputs for the UK, although has its limitations as selecting and adapting a climate region in the U.S. also means that the typical building and energy information, etc., are only applied to some extent.

Given the limitations described above, the energy effects model has not been previously used in the UK and was trialled for the first time in 2015 in the Bridgend CB, Tawe catchment and London i-Tree Eco studies to provide an indication of the likely impact of urban trees on energy use by buildings across these study areas. The results for Tawe catchment survey are presented on a non-numeric basis in Table 15 where '+' symbols indicate a (positive) energy saving, '-' symbols indicate more energy is required (a negative energy saving) and multiple symbols indicate an order of magnitude difference. Estimates for the cost savings are detailed below, though should be used only in light of the current limitations of the model.

Table 15. 'Direction of travel' indicators of the likely impact of urban trees across the Tawe catchment on energy use by domestic properties, where multiple symbols indicate an order of magnitude difference.

	Energy for:		
	Heating	**Cooling**	**Total**
Gas	++	(n/a)#	++
Electric	++	++	++
Carbon avoided	+	+	+
Total	**++**	**++**	**+++**

n/a as air conditioning units are typically electrical

With respect to a buildings use of energy for heating, trees that shelter buildings from the prevailing wind offer energy savings. Conversely, trees planted to the south and west can shade a building resulting in more energy being required for heating, especially where the canopy is dense and the height to canopy base is low restricting wintertime sun from falling on to the building. With respect to buildings use of energy for cooling, trees planted to the south and west and of sufficient height can shade a building preventing excessive heating and energy savings. For further details on the role of trees in energy use by buildings see Doick & Hutchings (2013).

Table 15 indicates that urban trees across the Tawe catchment provide shelter in the winter leading to energy savings (estimated at £61,000 per year across the Tawe catchment), as well as shading in the summer, resulting in a positive impact with respect to summertime air conditioning (estimated at £82,000 per year across the Tawe catchment). The overall summary suggests that the impact of the trees is positive, and has an estimated value of £143,000 per year across the Tawe catchment.

To improve the role of trees across the Tawe catchment with respect to further increases in efficient use of energy, the existing tree stock can be assessed for appropriate management, for example lifting of crown bases to allow the winter sun to warm homes. Given the current and projected climate of the Tawe catchment, adopting a strategic approach to future planting can lead to the urban forest of the Tawe catchment having an even greater positive impact on energy use. Homeowners and developers can follow published guidelines on the strategic placement of trees to reduce building energy use (see NHBC Foundation 2012).

Conclusions

The urban forest of the Tawe catchment provides valuable ecosystem services and improves the quality of life for local residents, making it a significant asset to the area. The Tawe catchment is estimated to contain 530,000 trees, with a tree density per hectare higher than the Welsh average. Tree canopy cover was comparable to other i-Tree Eco studies at 16%, and higher than neighbouring Bridgend's 12%. The Tawe catchment had a low number of large diameter trees (after small stature trees had been removed) with agricultural land, institutional land and golf courses containing the highest proportion of large trees. Large diameter trees are important because they tend to produce more ecosystem services and provide more habitat for wildlife. Furthermore, very few medium sized trees, with a 40-60 cm diameter, were sampled, suggesting there may be a shortage of large trees in the near future. The expected presence of large trees in the longer term, however, is good with a high abundance of small diameter trees and a good overall condition of the urban forest.

The ecosystem services provided by trees are on-going and, for services such as carbon storage, could become more valuable in the future as external factors change. Planning tree stocks to maintain a high level of ecosystem service delivery is, therefore, of paramount importance. The most common species tended to be pioneer species such as alder, willow and birch, a pattern also found in many other i-Tree Eco surveys and reflected by the high proportion of trees found on vacant land. Diversity, important for ensuring the resilience of urban trees against pests and diseases, was comparable to other UK i-Tree Eco surveys, but could be improved upon. The ten most abundant tree species in the Tawe catchment account for 62% of the population and three species (common alder, goat willow and downy birch) exceeded the recommended limit of 10% abundance. This could lower the resilience of the urban forest of the Tawe catchment, especially as alder is susceptible to *Phytophthora alni*. Furthermore, oak - the most significant tree in terms of carbon sequestration due to its prevalence, is at risk from acute oak decline.

Diversity was highest on residential land and in parks, associated with highest abundance of trees. The Tawe catchment could improve the diversity of the urban forest by targeting areas with lower diversity. Many of these, such as institutional properties, transport corridors and multi-family residential areas tend to be proactively managed, easing this process.

South Wales has been hit hard by numerous pest and diseases most notably *Phytophthora* spp and more recently *Chalara*. Medium risk (due to climate), but high impact pests such as the Asian longhorn beetle, although not currently present in the UK as outbreaks have been contained, could affect many of the trees of the Tawe catchment. Planning an urban forest that is resilient to a broad range of pests and diseases is key and will be aided by maintaining high tree diversity across the Tawe catchment, taking into account trees on private property in addition to those in the public realm.

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

The net carbon sequestered annually by the Tawe catchment's trees was 3,000 tonnes. This information and the other values for the benefits of trees highlighted in this report can be used to shape policy or local targets for protecting existing trees and encouraging the expansion of the urban forest. The annual carbon sequestration by trees can be compared to carbon emitting practices, such as annual emissions by homes within the Tawe catchment, and could then be used to inform tree planting to offset a proportion of the CO_2 emissions. In this way, tangible goals can be incorporated into local policy.

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

This study is also limited given that it is a snapshot of the forest in 2014. Monitoring, using the same or a comparable technique, will allow variations to be taken into account and in the long term could be used to illustrate dynamic processes such as climate change and allow a robust long-term picture to be built. It is recommended that an i-Tree Eco survey is conducted every 5-10 years to support the management and planning of the Tawe catchment's urban forest.

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

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Appendix I - Detailed Methodology

i-Tree Eco Models and Field Measurements

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

- Urban forest structure (e.g., species composition, tree health, leaf area, 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.
- Replacement cost of the forest, as well as the value for air pollutant removal, rainwater interception and carbon storage and sequestration.
- Potential impact of potential emerging pests and diseases

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

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

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

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

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

This 'avoided charges' cost is a conservative estimate of the total 'avoided charges' across the full survey area as it does not account for infrastructural, operational and treatment charges linked to surface water management by, for example, Local Authorities, Internal Drainage Boards and Natural Resources Wales. Therefore, the Standard volumetric rate – Surface water rebated per cubic metre value of £1.3238 is used as a representative value of the avoided cost of treating surface water runoff across the whole survey area.

Table 16. Land use definitions (adapted from the i-Tree Eco v5 manual).

Land-use	Definition
Residential	Freestanding structures serving one to four families each. (Family/person domestic dwelling. Detached, semi-detached houses, bungalows, terraced housing)
Multi-family residential	Structures containing more than four residential units. (Flats, apartment blocks)
Commercial/Industrial	Standard commercial and industrial land uses, including outdoor storage/staging areas, car parks not connected with an institutional or residential use. (Retail, manufacturing, business premises)
Park	Parks, includes unmaintained as well as maintained areas. (Recreational open space, formal and informal)
Cemetery	Includes any area used predominantly for interring and/or cremating, including unmaintained areas within cemetery grounds
Golf Course	Used predominately for golf as a sport
Agriculture	Cropland, pasture, orchards, vineyards, nurseries, farmsteads and related buildings, feed lots, rangeland, woodland. (Plantations that show evidence of management activity for a specific crop or tree production

	are included)
Vacant	Derelict, brownfield or current development site. (Includes land with no clear intended use. Abandoned buildings and vacant structures should be classified based on their original intended use)
Institutional	Schools, hospitals/medical complexes, colleges, religious buildings, government buildings,
Utility	Power-generating facilities, sewage treatment facilities, covered and uncovered reservoirs, and empty stormwater runoff retention areas, flood control channels, conduits
Water/wetland	Streams, rivers, lakes, and other water bodies (natural or man-made). Small pools and fountains should be classified based on the adjacent land use.
Transportation	Includes limited access roadways and related greenspaces (such as interstate highways with on and off ramps, sometimes fenced); railroad stations, tracks and yards; shipyards; airports. If plot falls on other type of road, classify according to nearest adjacent land use.
Other	Land uses that do not fall into one of the categories listed above. This designation should be used very sparingly as it provides very little useful information for the model.

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

Calculating current carbon storage: biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak, 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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

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

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

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

Calculating building energy use savings: the UFORE Methods paper states that the UFORE-E model estimates the effects of trees on building energy use and consequent emissions of carbon from power plants. For each tree within 18 m of a one or two story residential building, information on distance and direction to the building are recorded. Information for trees smaller than 6 m in height or greater than 18 m from a building are considered to have no effect on building energy use. The amount of carbon emissions from power plants avoided due to the presence of trees is calculated based upon tree size, distance, direction to building, climate region, leaf type (deciduous or evergreen) and percent cover of buildings and trees on the plot. The amount of carbon avoided is categorized into MWh (Mega Watt hours) for cooling, and MBtu (Mega British Thermal Unit[15]) and MWh for heating avoided due to tree energy effects.

Trees affect the energy performance of a building through shade, windbreak effects and local climate cooling effect. The calculations use default energy effects per tree for each climate region, vintage building types (period of construction), tree size class, distance from building, energy use (heating or cooling) and/or leaf type (deciduous or evergreen) depending upon the energy effect being modelled. For example, default shading and climate effect values are applied to all trees, while heating avoided through windbreak energy effects are only assigned to evergreen trees. Shading effect default values are only given in the model for one vintage building type (post-1980), with vintage adjustment factors applied to obtain shading effect values for all other vintage types.

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

[15] A standard unit of measurement used to denote both the amount of heat energy in fuels and the ability of appliances and air conditioning systems to produce heating or cooling. A BTU is the amount of heat required to increase the temperature of a pint of water by one degree Fahrenheit. Since Btus are measurements of energy consumption, they can be converted directly to kilowatt-hours (3412 Btus = 1 kWh) or joules (1 Btu = 1,055.06 joules). MBtu stands for one million Btus. Ref:
https://www.energyvortex.com/energydictionary/british_thermal_unit_(btu)__mbtu__mmbtu.html

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 use 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 the Tawe catchment 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.

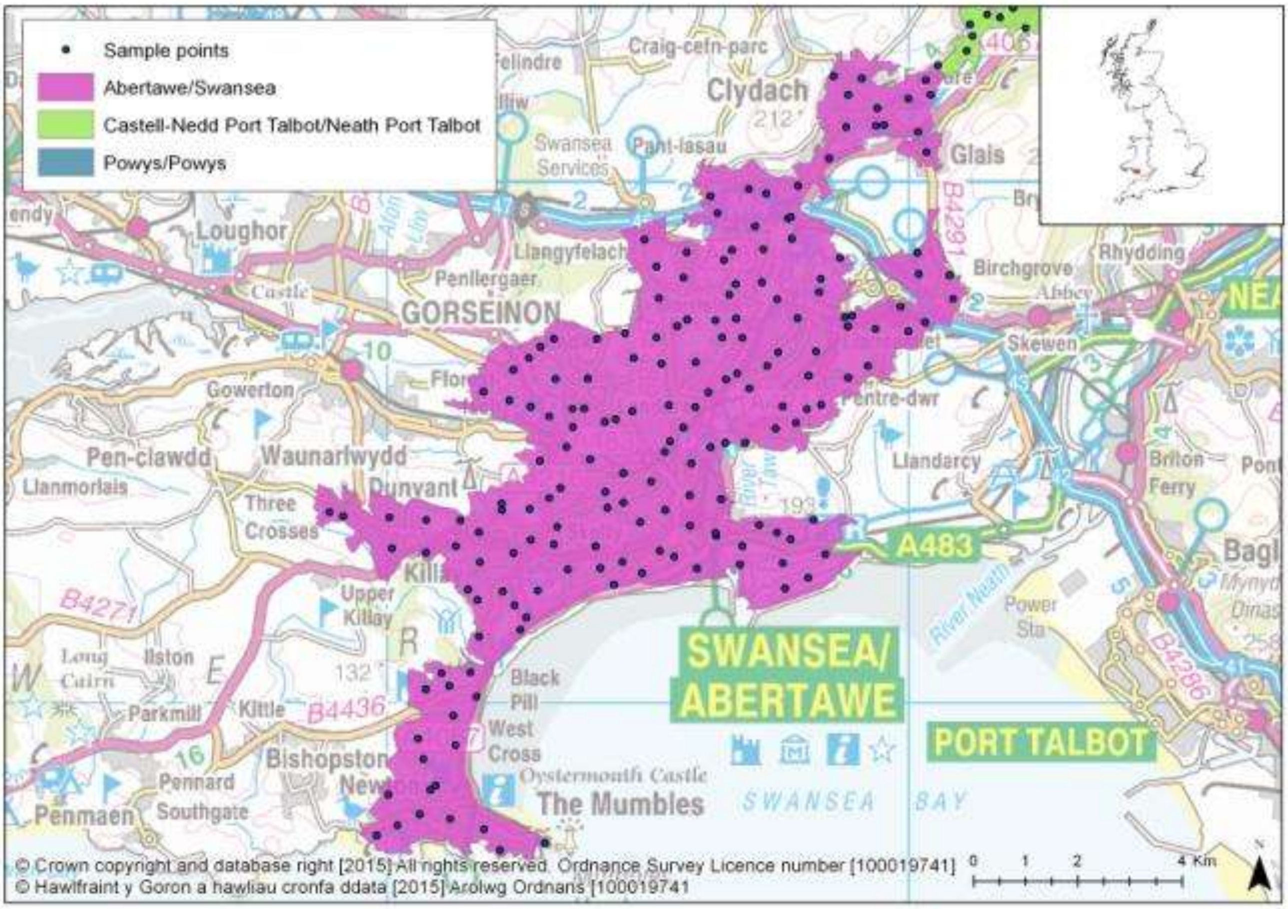
For trees found in open spaces, trees were divided into those with 100% exposure to light and those that did not. On the basis that trees in open spaces are less intensively managed, an 80% functionality factor was applied to all individual open grown trees. For trees without 100% exposure to light the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

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

Appendix II – Swansea

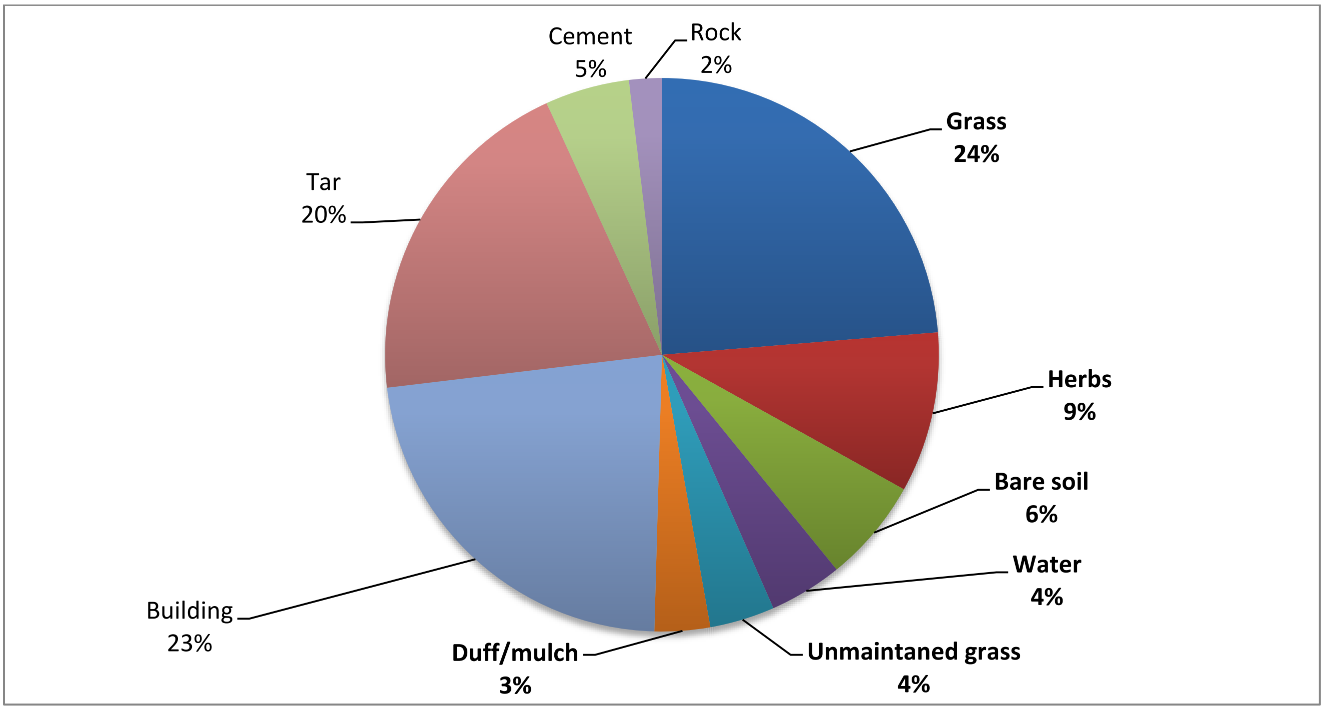
Sample Area

The results presented in this Appendix are based on 181 survey plots. With a survey sample area of 5,912 ha, this provides a sample density of 1 plot per 33 ha. Below the results are presented for the City of Swansea; and can be treated as statistically representative as well as proportional to the other sample sub-areas (Neath Port Talbot CB and Powys County).



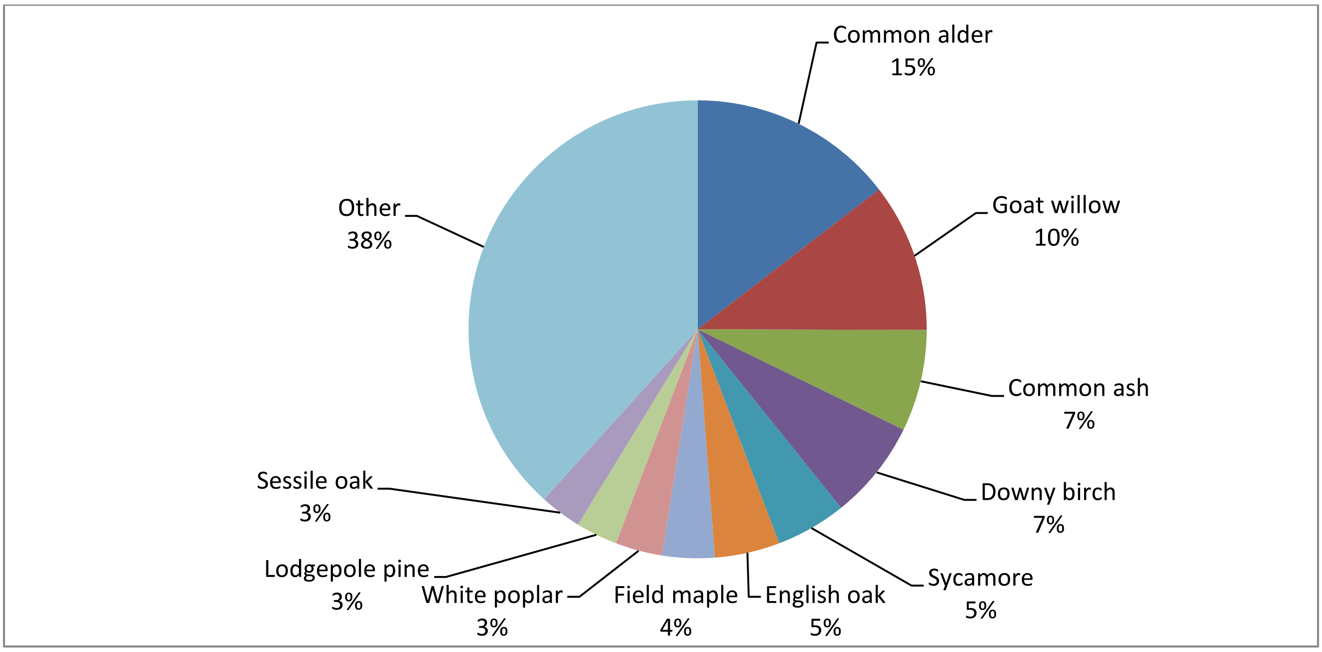
Plots in the urban areas of the Tawe catchment study area that are within Swansea city's urban areas. In total 181 plots were sampled (basemap: ©OpenStreetMap contributors).

Tree canopy cover across the Swansea sample area is 16.6%, which is highly comparable to the Welsh average of 16.8% (Fryer 2014).

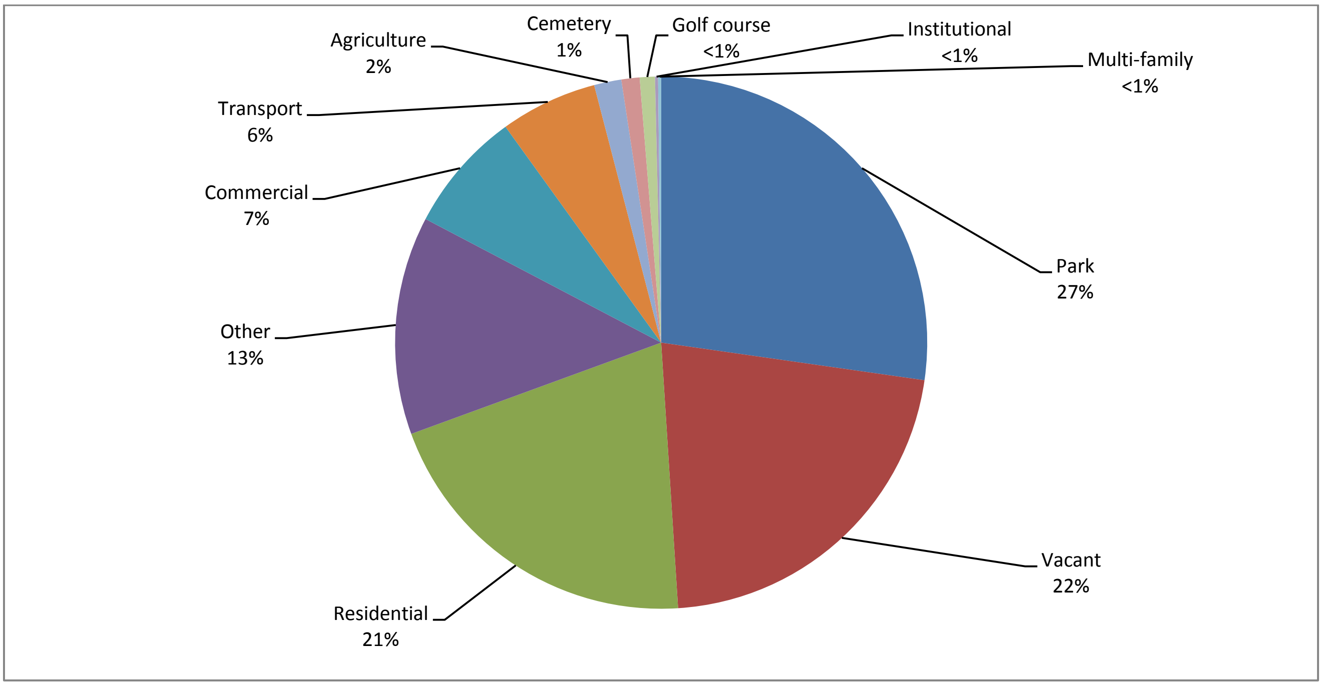


Types of ground cover encountered in Swansea. Bold labels denote permeable surfaces, the remainder are non-permeable.

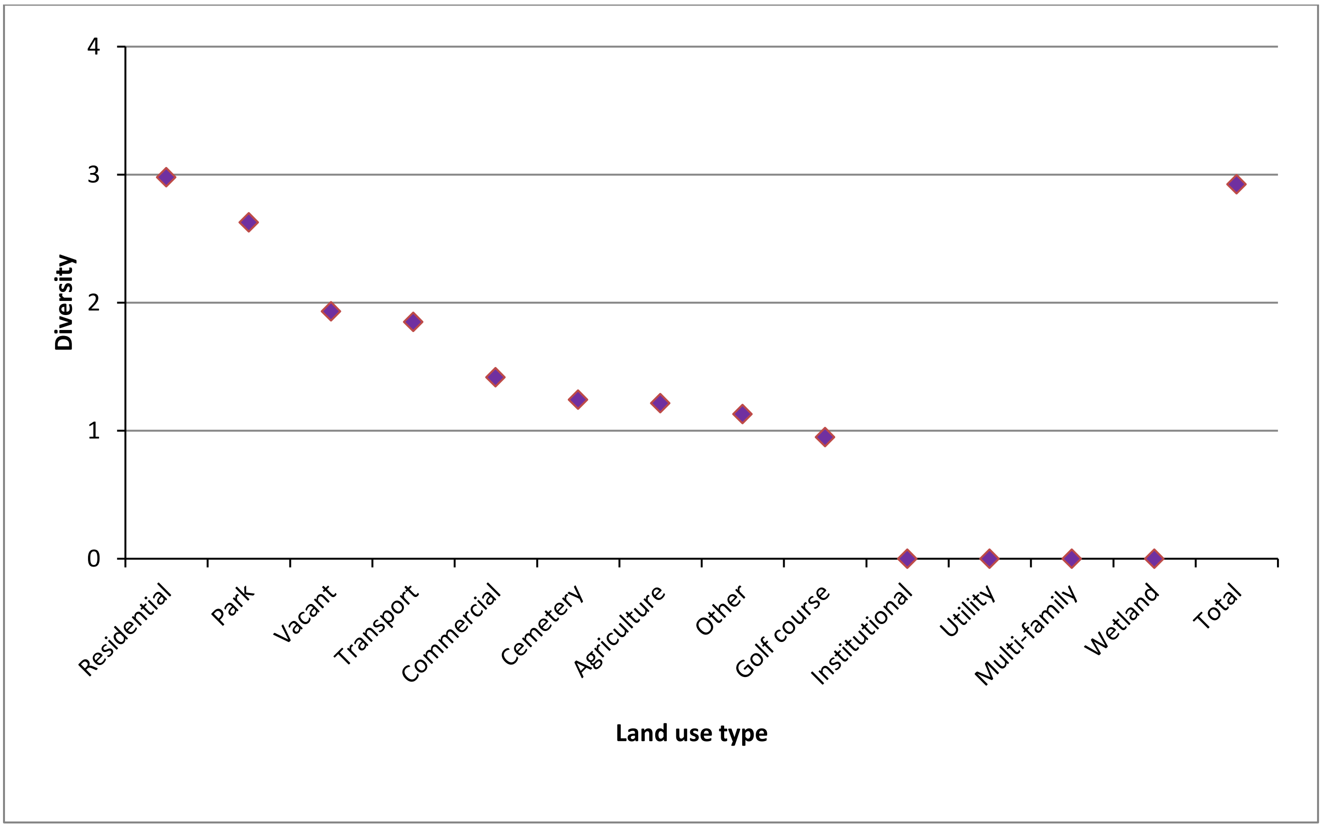
Urban forest structure



Breakdown of trees species in Swansea.



Land use types on which trees were present. Land use types where no trees were found are omitted.

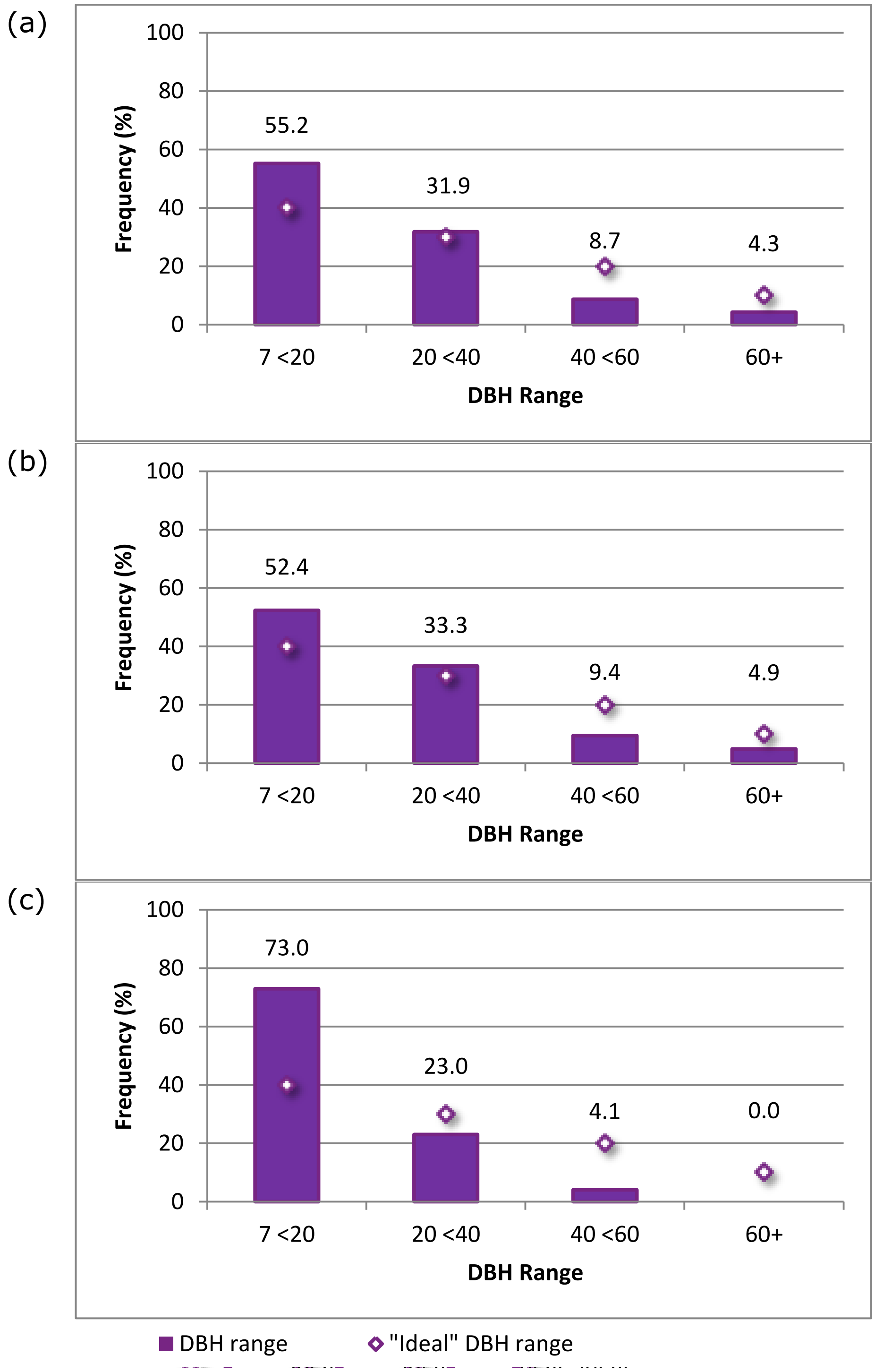


Shannon wiener diversity index values for trees on different land use types in Swansea.

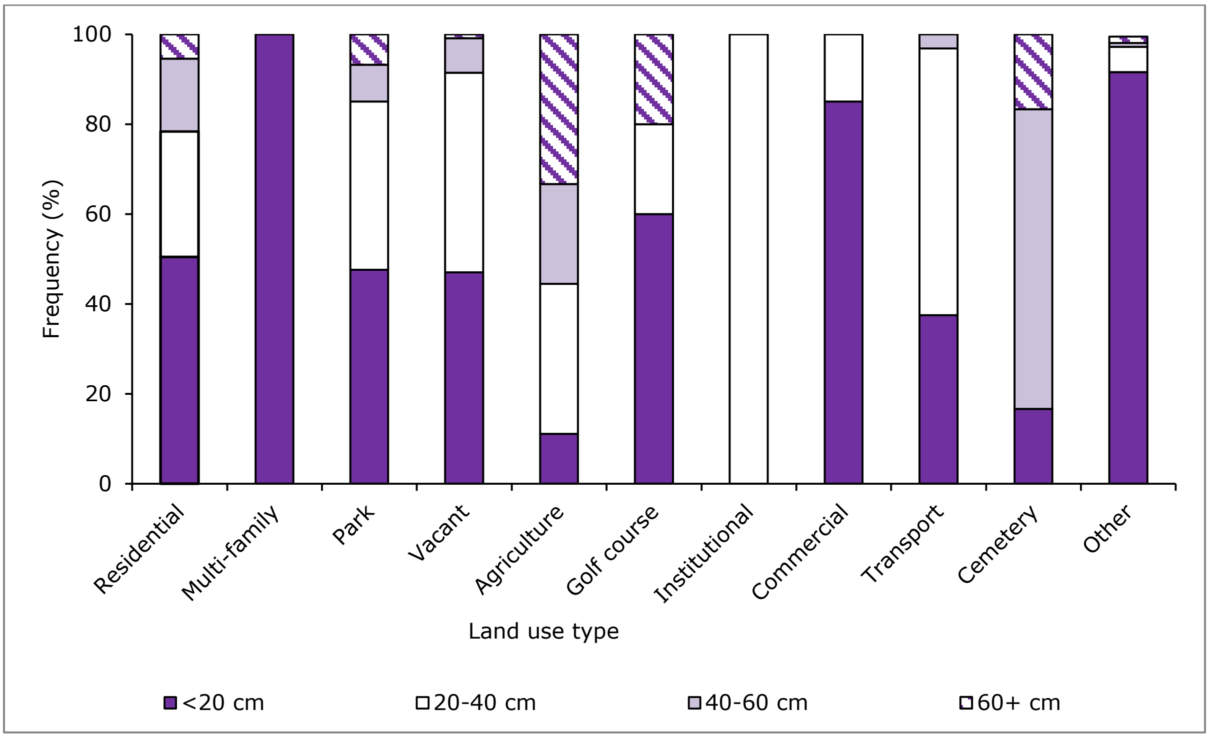
Top three frequency tree species, genus and family.

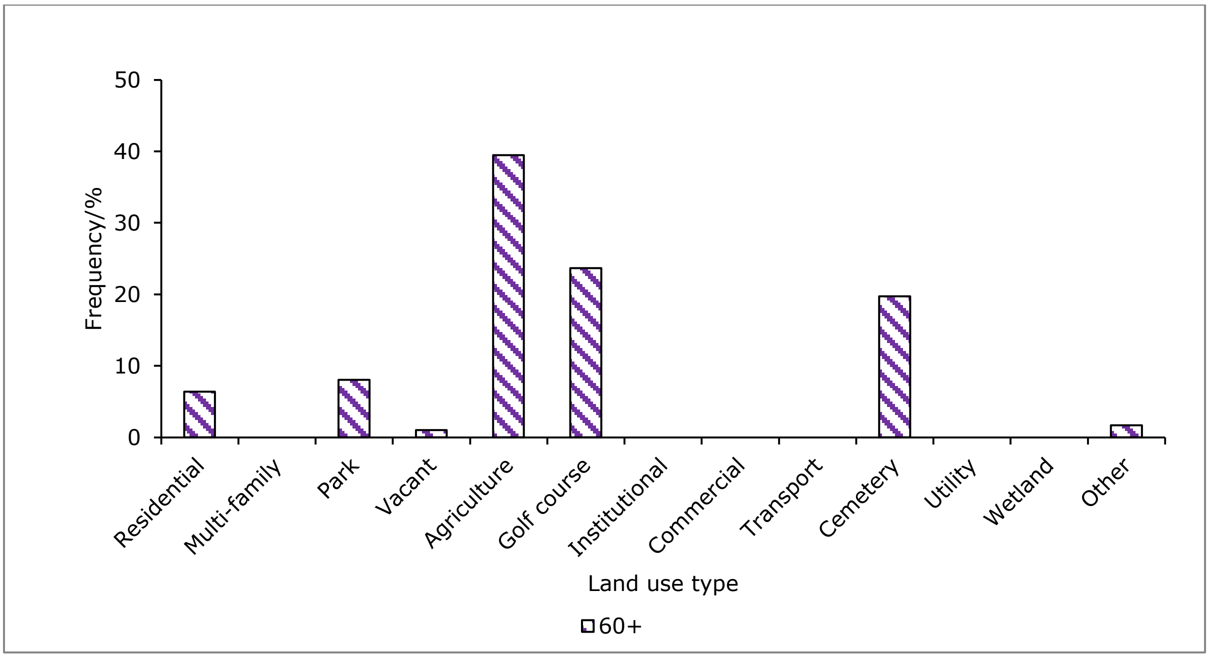
Species	Common Alder	**14.5 %**	Goat willow	**10.5 %**	Common Ash	7.2%
Genus	Alnus	17.4 %	Salix	13.3%	Betula	10.0%
Family	Betulaceae	27.3 %	Salicaceae	19.0%	Aceraceae	9.6 %

Bold entries denote groups exceeding the guidelines outlined by Santamour (1990) of no. species exceeding 10%, no. genus 20% and no. family 30%



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





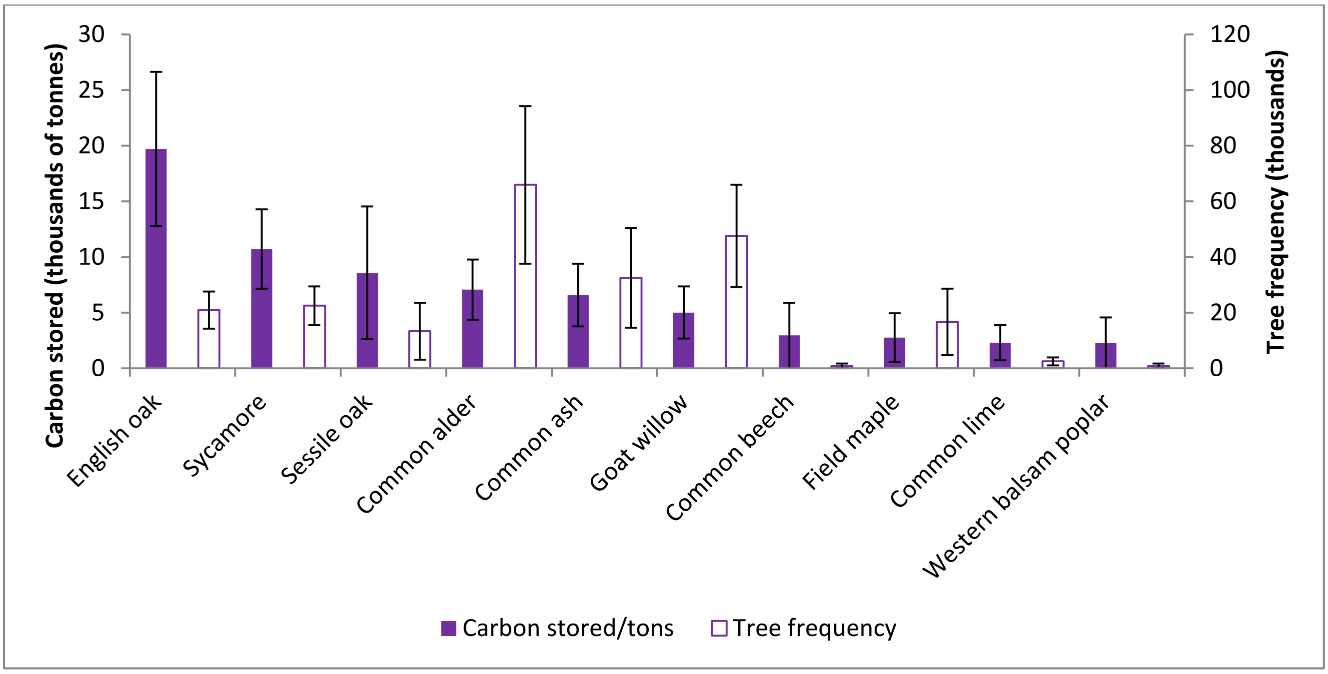
Proportion of diameter size classes per land use type. A missing value denotes land use types where no trees were found.

Ecosystem Services

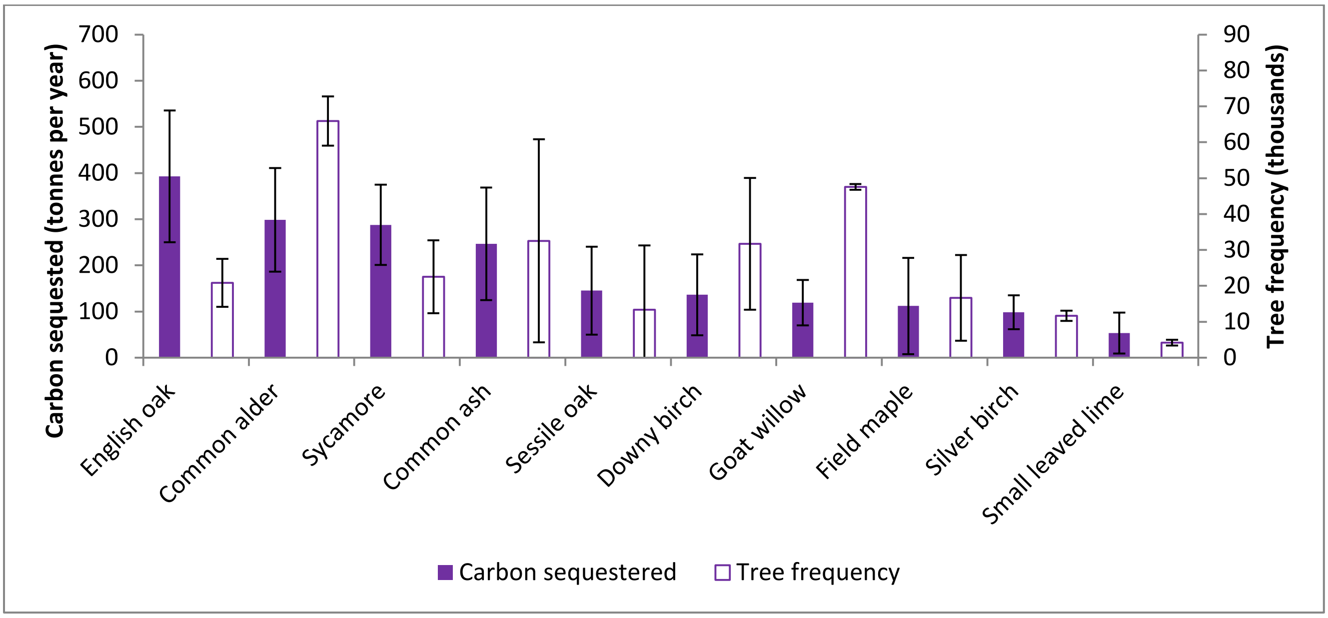
Avoided Runoff for Trees in Swansea by Land Use.

Land Use	Swansea	Tawe catchment
Number of trees	453,030	535,458
Leaf area (km^2)	39.7	48
Avoided runoff (litres / yr)	207,504,000	252,200,000
Avoided runoff Value (£)	274,694	333,865

Rain avoided runoff is calculated by the price £1.3238 m^{-3}



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



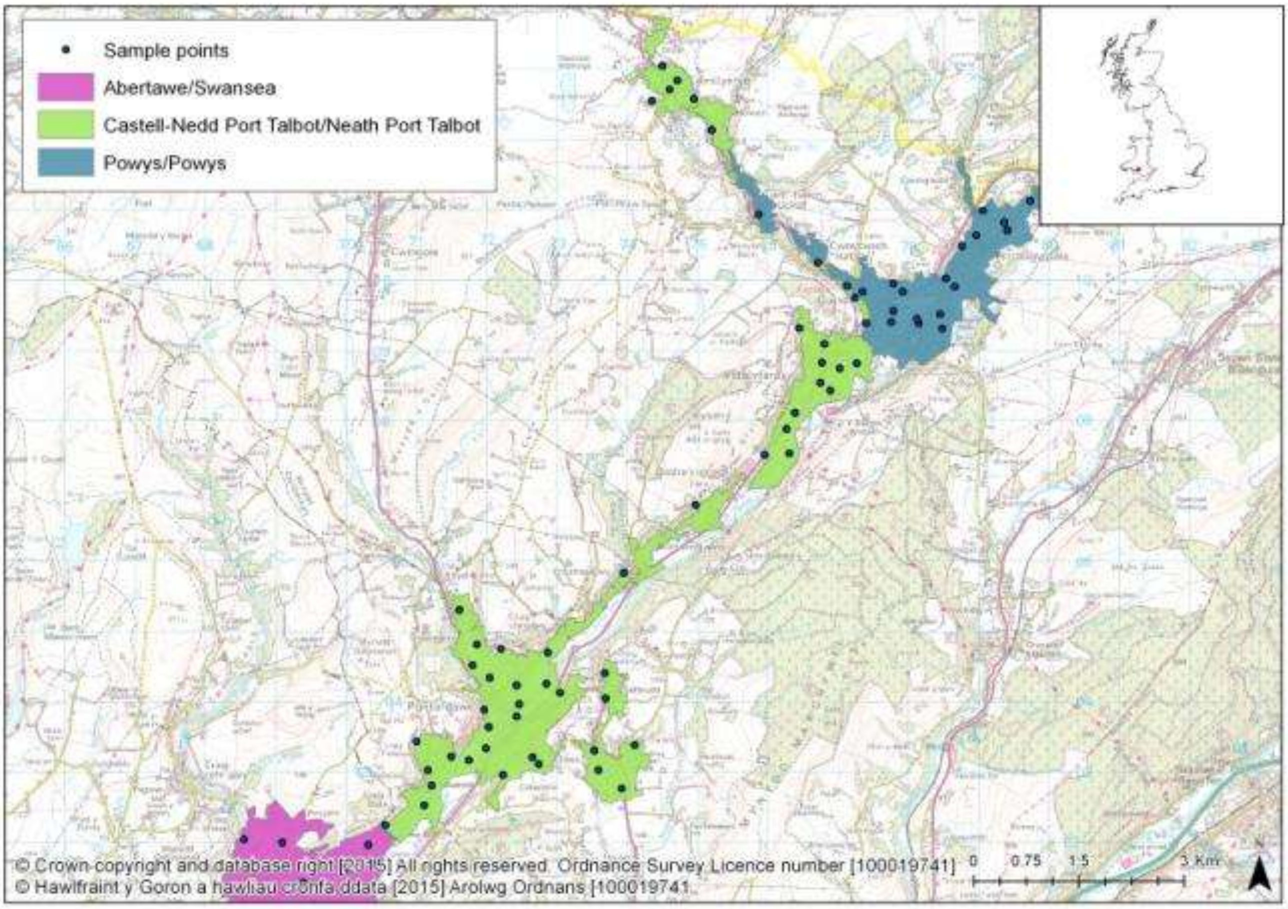
Carbon sequestered per year by the ten trees with highest rates, along with their frequency. Error bars denote standard error of the mean (SEM).

It is estimated that urban trees within the Swansea city sample area store 90,000 tonnes of carbon in their wood. Based on the central scenario for non-traded carbon, this carbon is currently worth an estimated £20.4 million; and is forecast to be worth £43.7 million in 2050; based on the UK government’s non-traded carbon valuation method and assume the urban forest remains unchanged until 2050. The net amount of carbon sequestered by these trees is 2,610 tonnes per year; estimated to be worth £579,000.

Appendix III – Neath Port Talbot

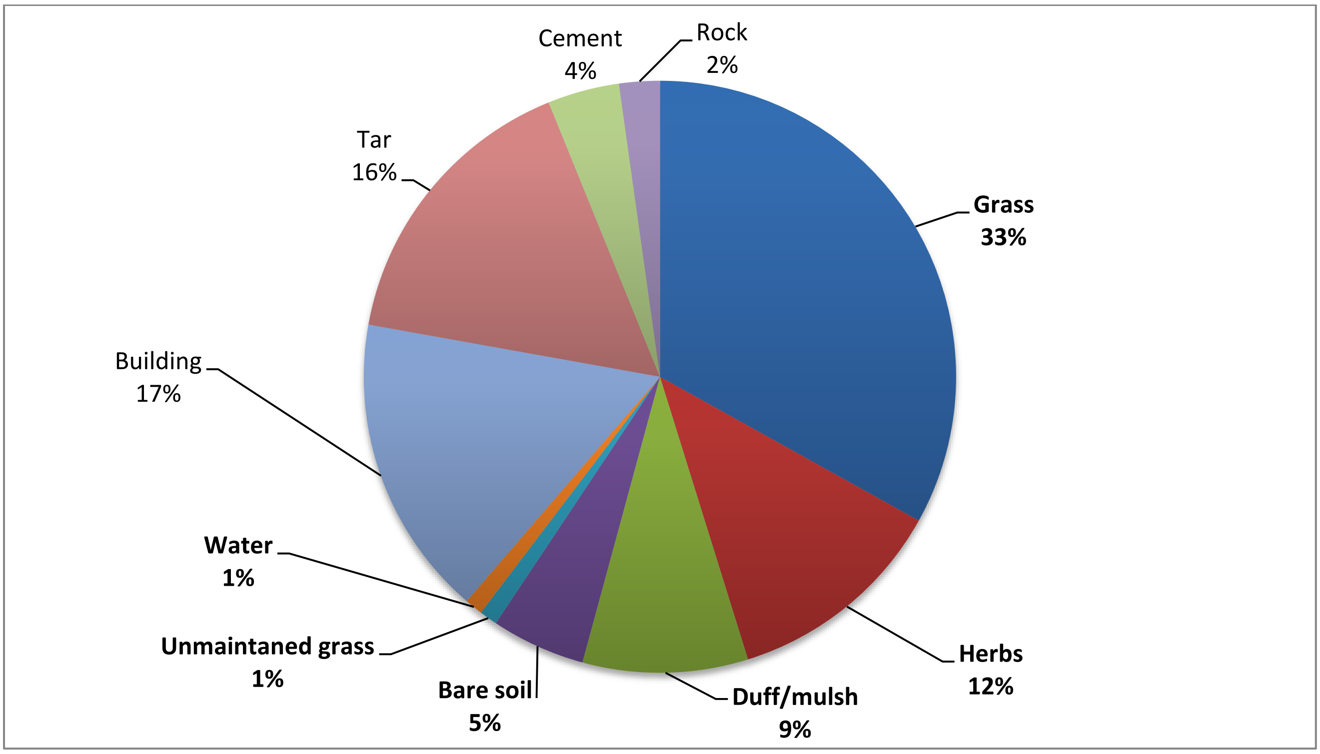
Sample Area

The Neath Port Talbot sub-sample area covers 719 ha and is shown in the Figure below. While 51 survey plots in this area provides a sample plot density of 1 plot per 14 ha, 51 plots is insufficient to provide a statistically robust analysis of the urban forest of Neath Port Talbot. As such, results should be treated with caution. They are, however, proportional to the other sample sub-areas (Swansea city and Powys County).



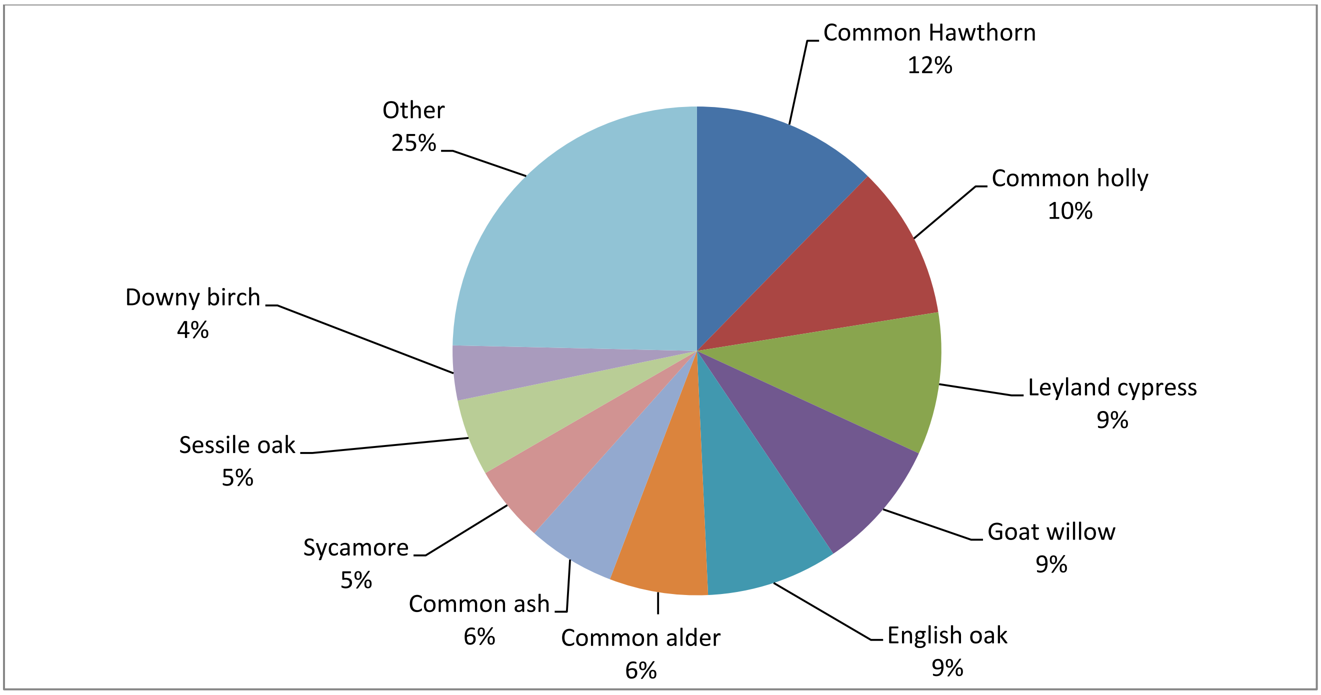
Plots in the urban areas of the Tawe catchment study area that are within Neath Port Talbot's county boundary. In total 51 plots were sampled (basemap: ©OpenStreetMap contributors).

Tree canopy cover across the Neath Port Talbot sample area is 14.3%, which is lower than the Welsh average of 16.8% (Fryer 2014).

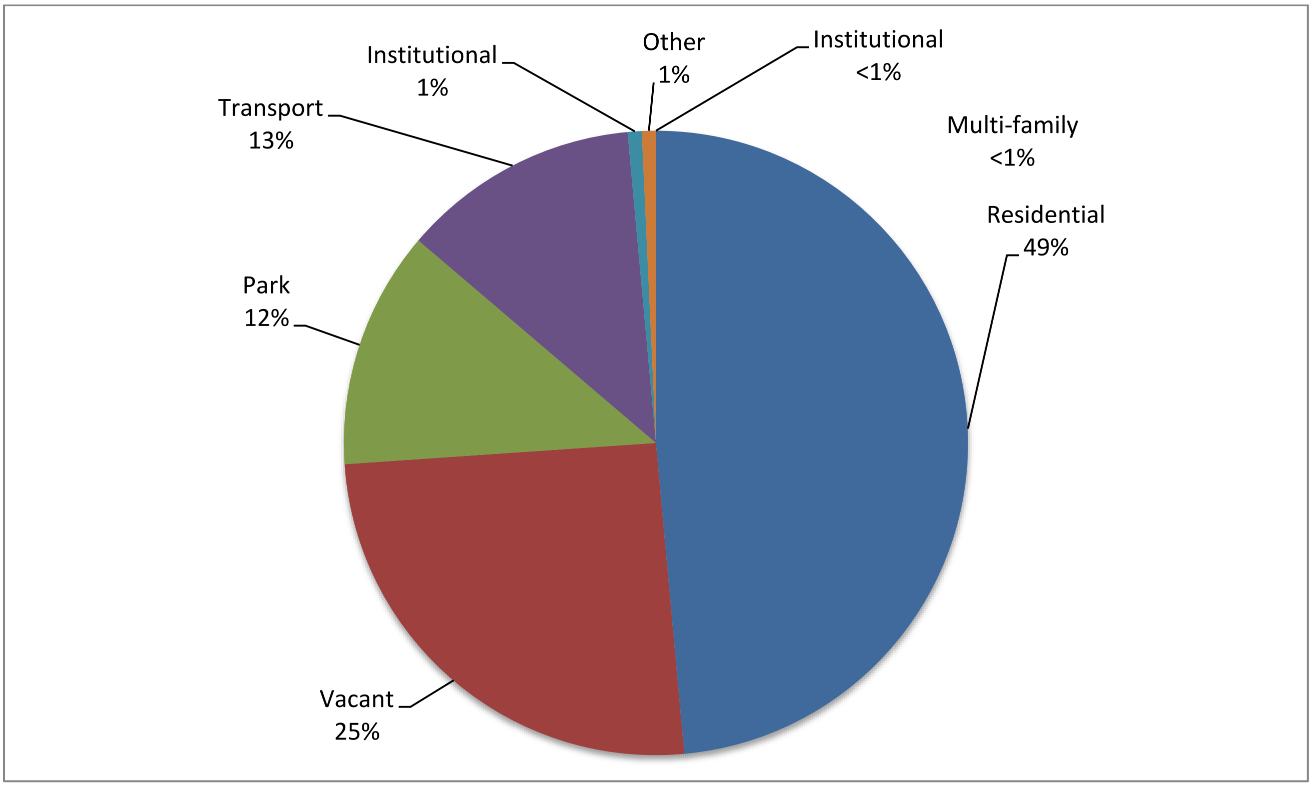


Types of ground cover encountered in Neath Port Talbot. Bold labels denote permeable surfaces, the remainder are non-permeable.

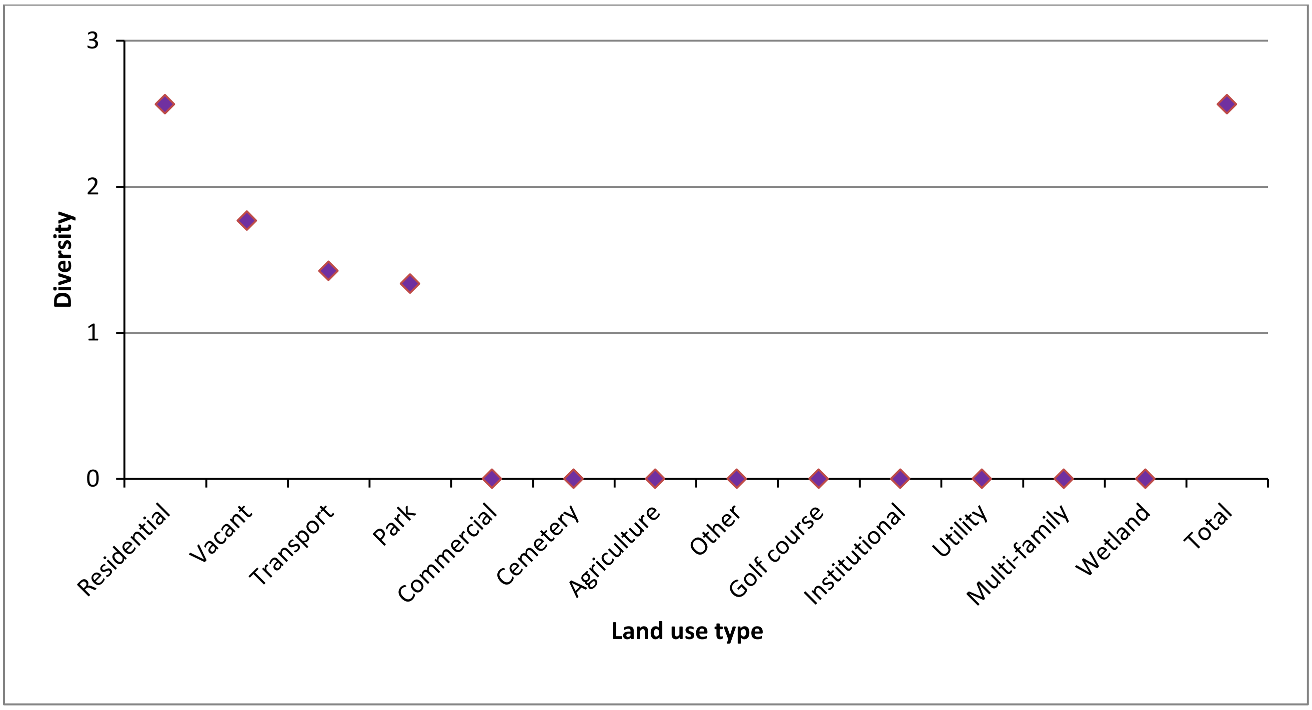
Urban forest structure



Breakdown of trees species in Neath Port Talbot.



Land use types on which trees were present. Land use types where no trees were found are omitted.

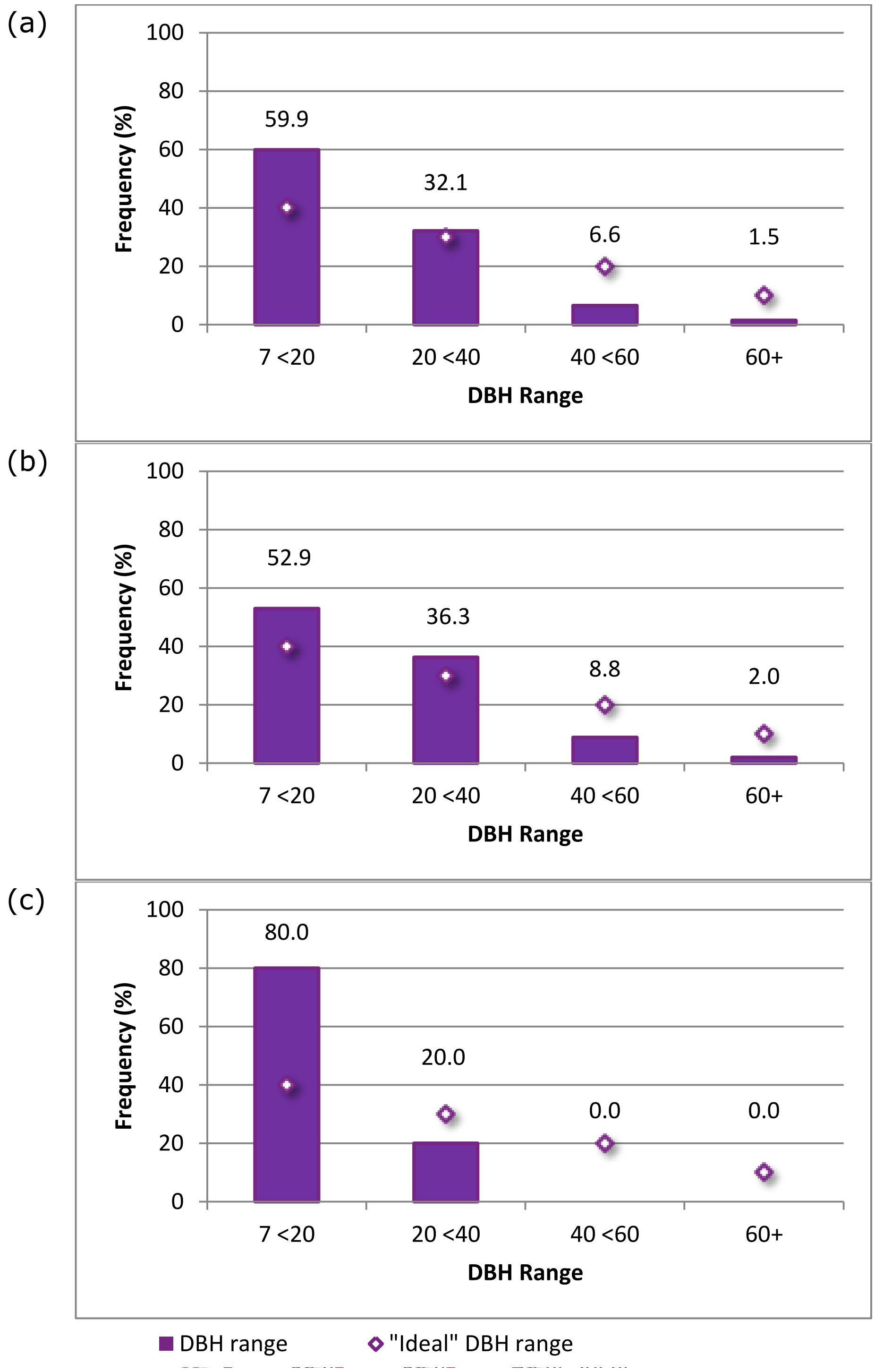


Shannon wiener diversity index values for trees on different land use types in Neath Port Talbot.

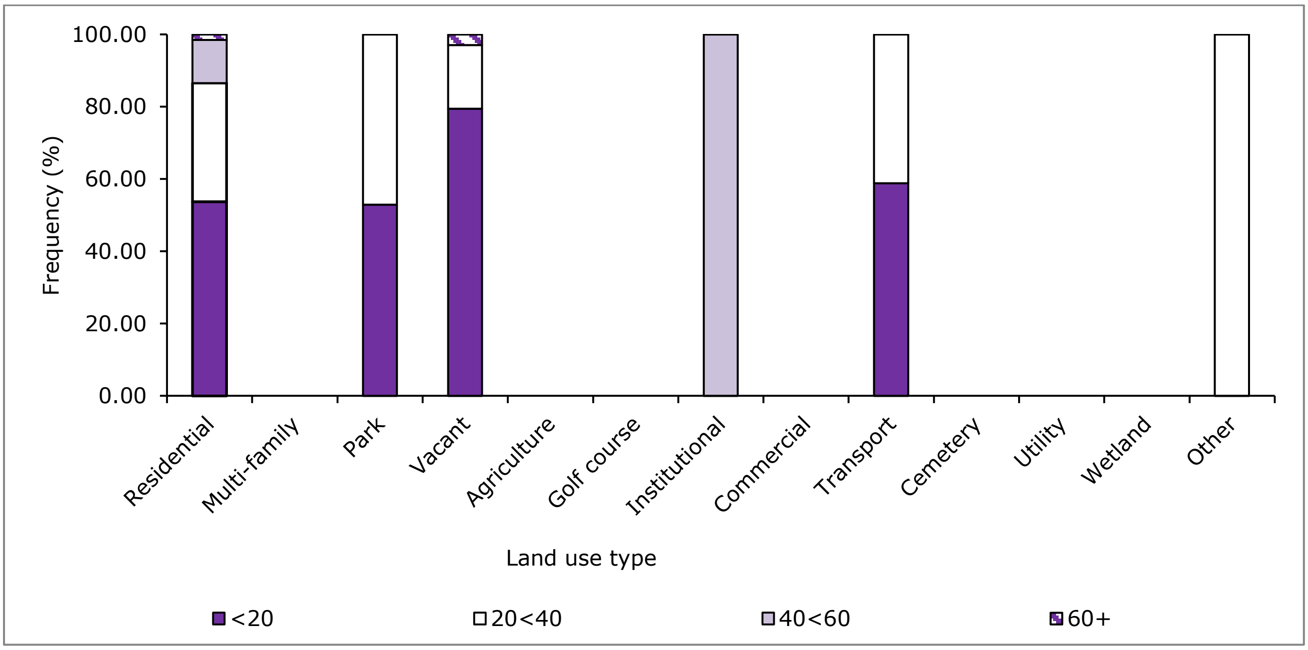
Top three frequency tree species, genus and family.

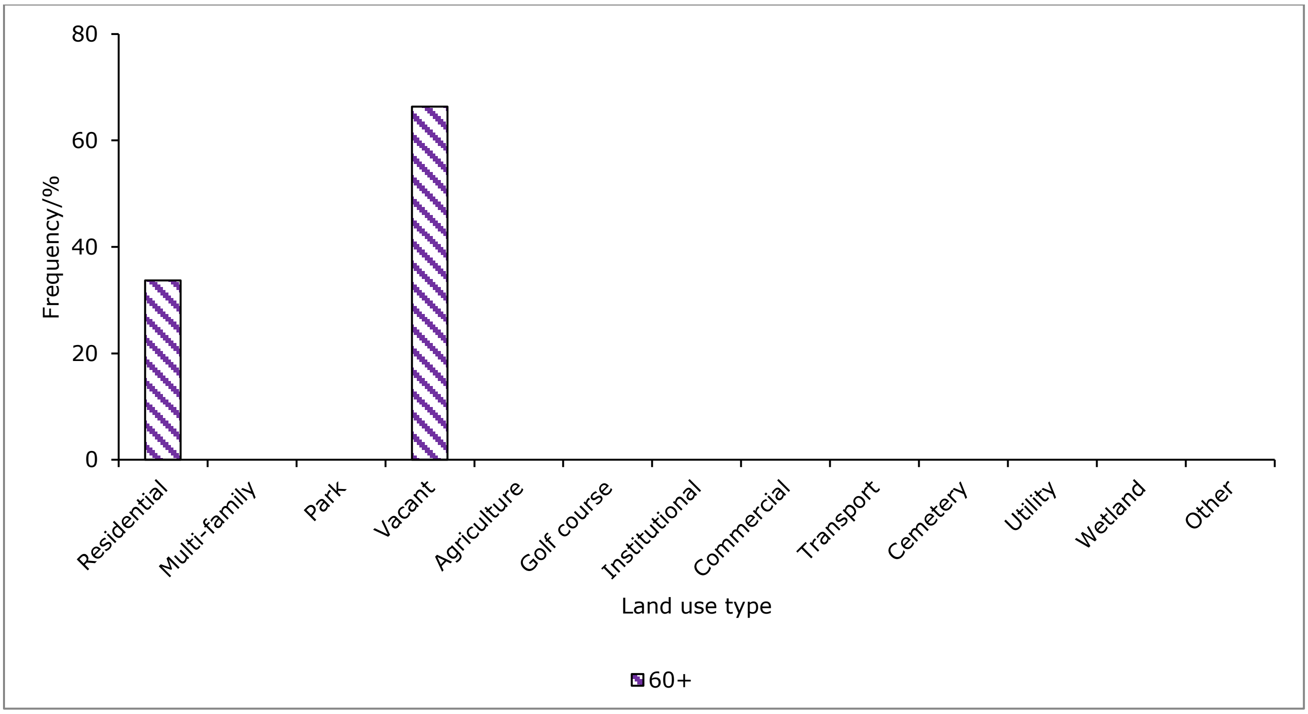
Species	Hawthorn	**12.3 %**	Holly	**10.1 %**	Leyland Cypress	9.4%
Genus	Quercus	13.9 %	Crataegus	13.1 %	Salix	10.9 %
Family	Rosaceae	17.5 %	Betulaceae	16.8 %	Fagaceae	14.6 %

Bold entries denote groups exceeding the guidelines outlined by Santamour (1990) of no. species exceeding 10%, no. genus 20% and no. family 30%



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





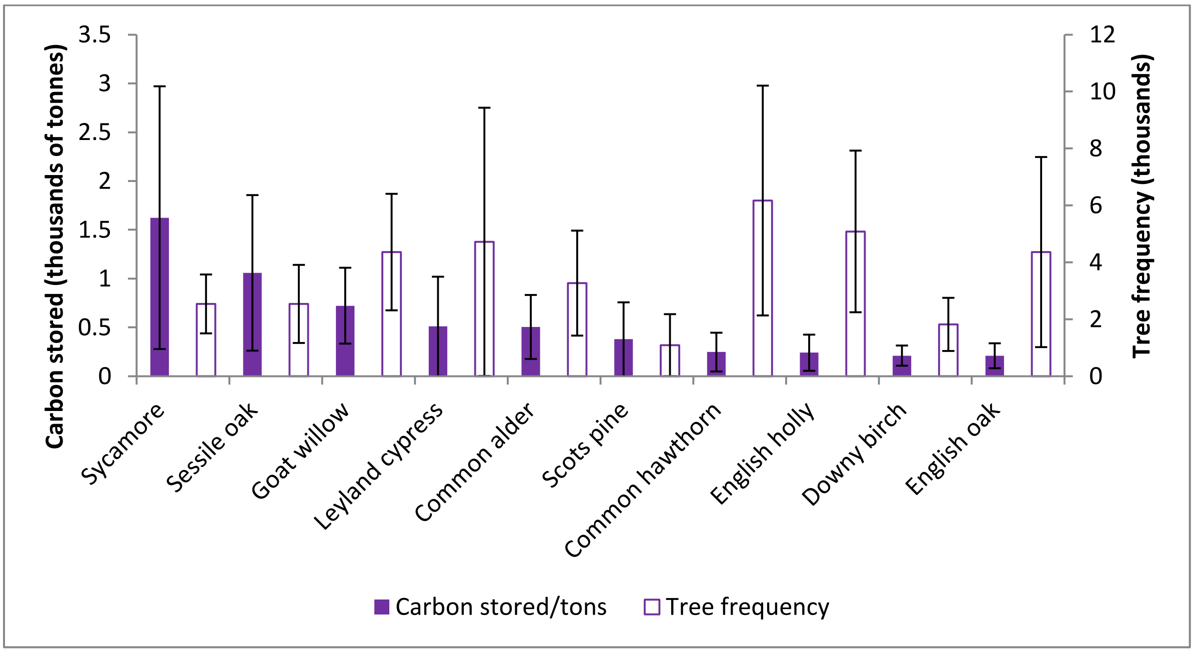
Proportion of diameter size classes per land use type for (a) all DBH size classes and (b) 60cm+ DBH only. A blank denotes land use types where no trees were found.

Ecosystem Services

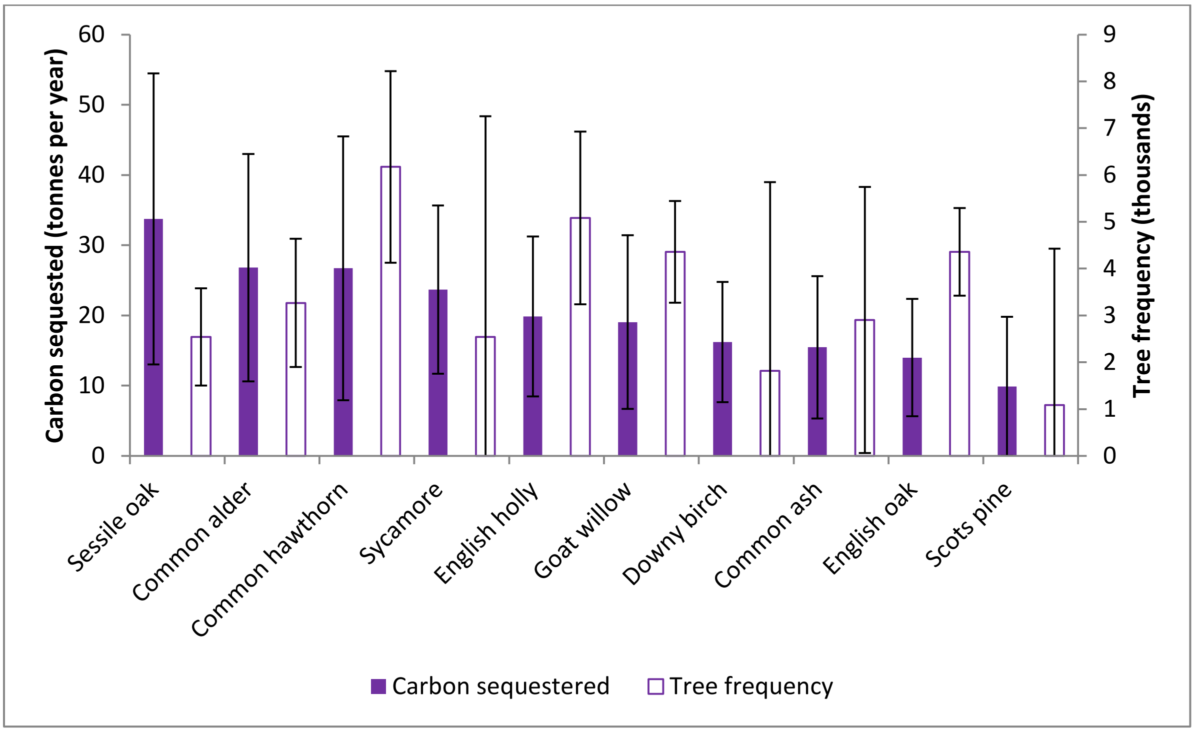
Avoided Runoff for Trees in Neath Port Talbot by Land Use.

Land Use	Neath Port Talbot	Tawe catchment
Number of trees	50,112	535,458
Leaf area (km^2)	4.7	48
Avoided runoff (litres / yr)	24,444,000	252,200,000
Avoided runoff Value (£)	32,359	333,865

Rain avoided runoff is calculated by the price £1.3238 m^{-3}



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



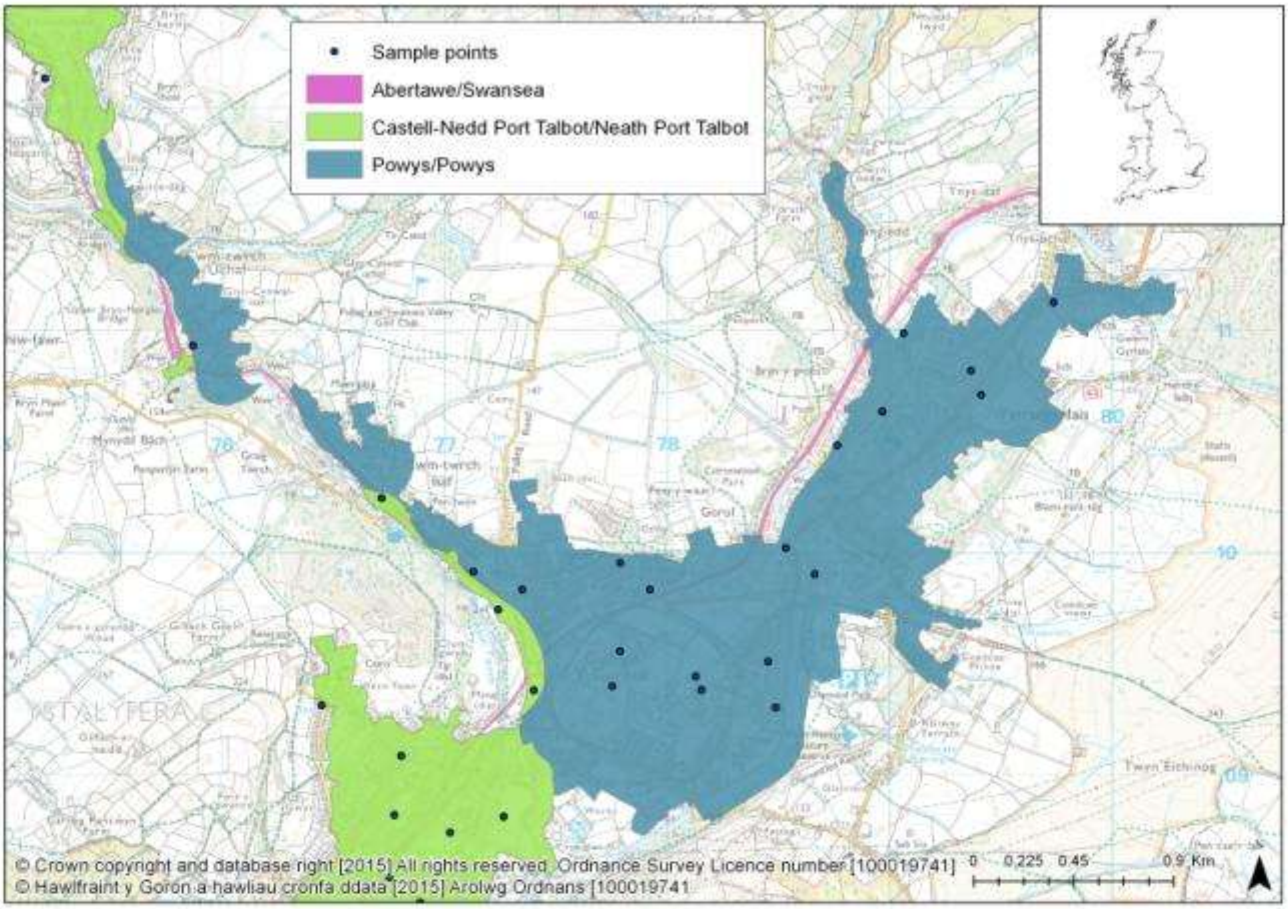
Carbon sequestered per year by the ten trees with highest rates, along with their frequency. Error bars denote standard error of the mean (SEM).

It is estimated that trees in Neath Port Talbot's urban forest store a total of 6,680 tonnes of carbon in their wood. Based on the central scenario for non-traded carbon, this carbon is currently worth an estimated £1.51 million; and is forecast to be worth £3.73 million in 2050. These values are based on the UK government's non-traded carbon valuation method and assume that the structure of the urban forest remains unchanged between now and 2050.The net amount of carbon sequestered by these trees is 250 tonnes per year; estimated to be worth £55,500.

Appendix IV – Powys

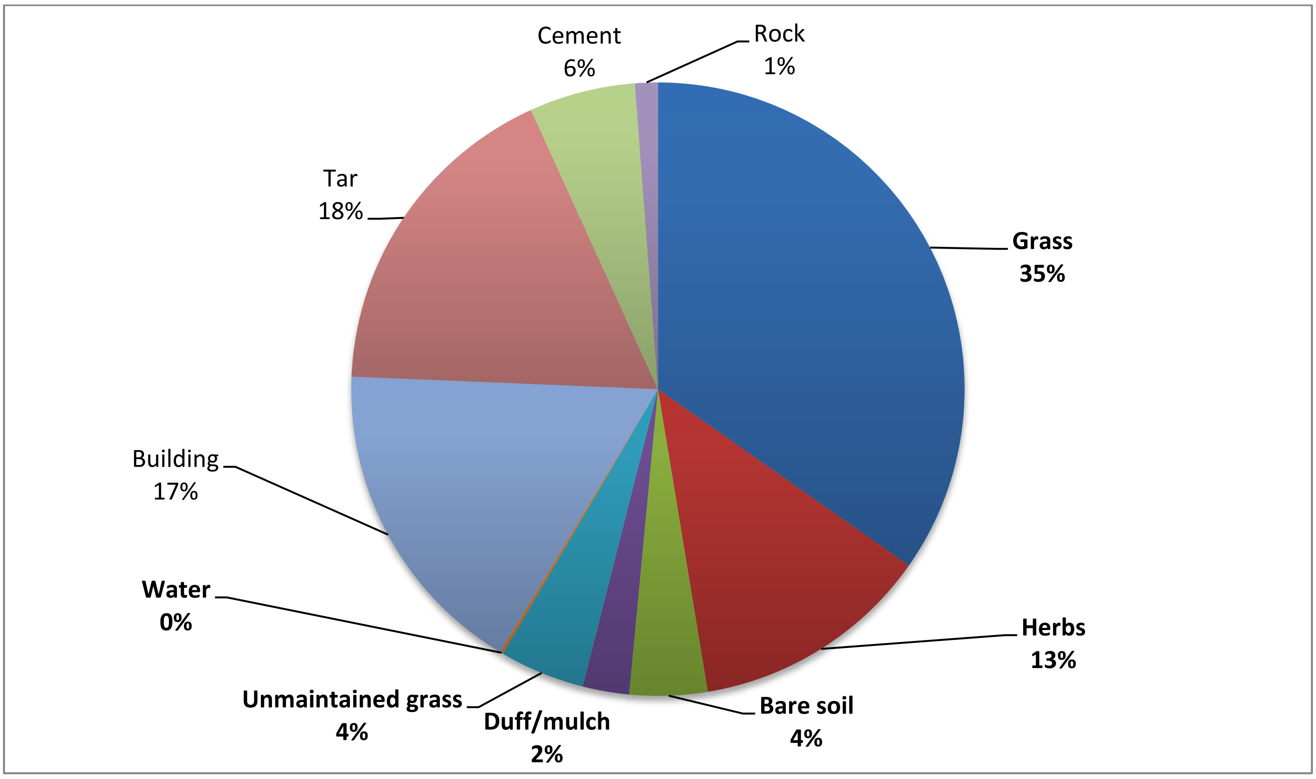
Sample Area

The Powys sub-sample area covers 308 ha and is shown in the Figure below. While 20 survey plots in this area provides a sample plot density of 1 plot per 15 ha, 20 plots is insufficient to provide a statistically robust analysis of the urban forest of Powys. As such, results should be treated with caution. They are, however, proportional to the other sample sub-areas (Swansea city and Neath Port Talbot CB).



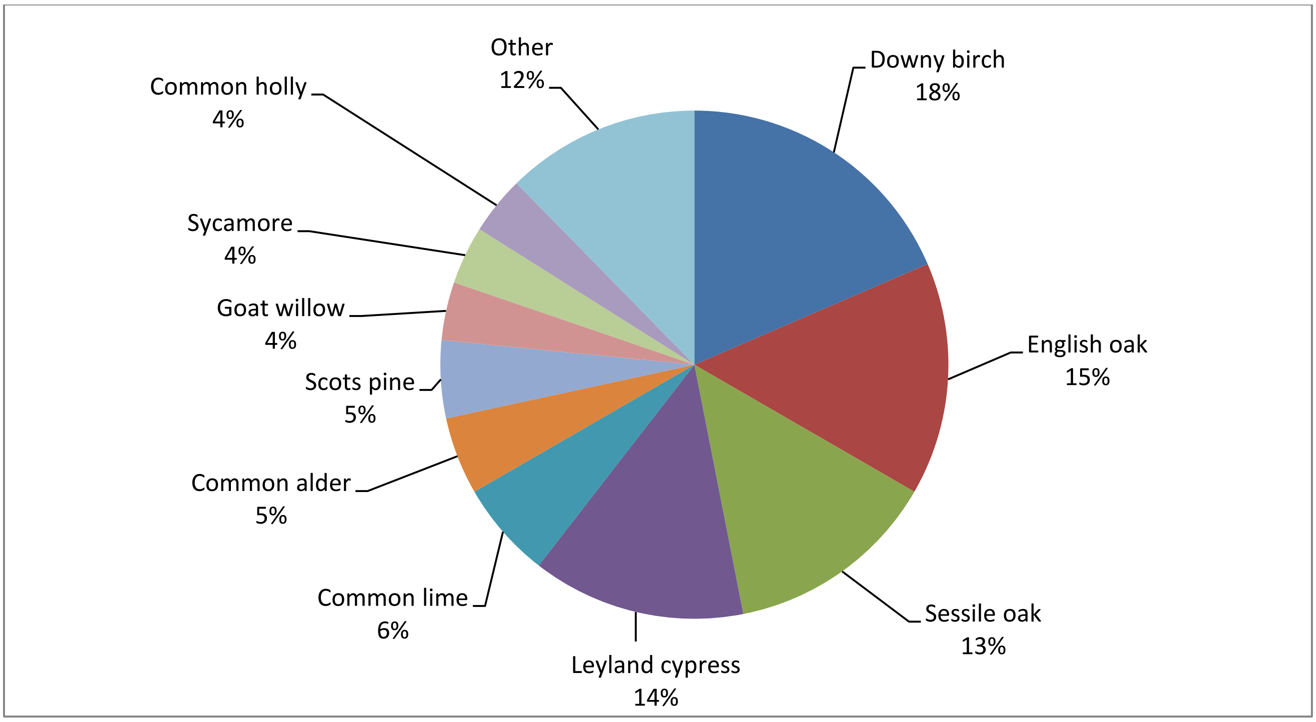
Plots in the urban areas of the Tawe catchment study area that are within Powys' county boundary. In total 20 plots were sampled (basemap: ©OpenStreetMap contributors).

Tree canopy cover across the Powys sample area is 18.6%, which is higher than the Welsh average of 16.8% (Fryer 2014).

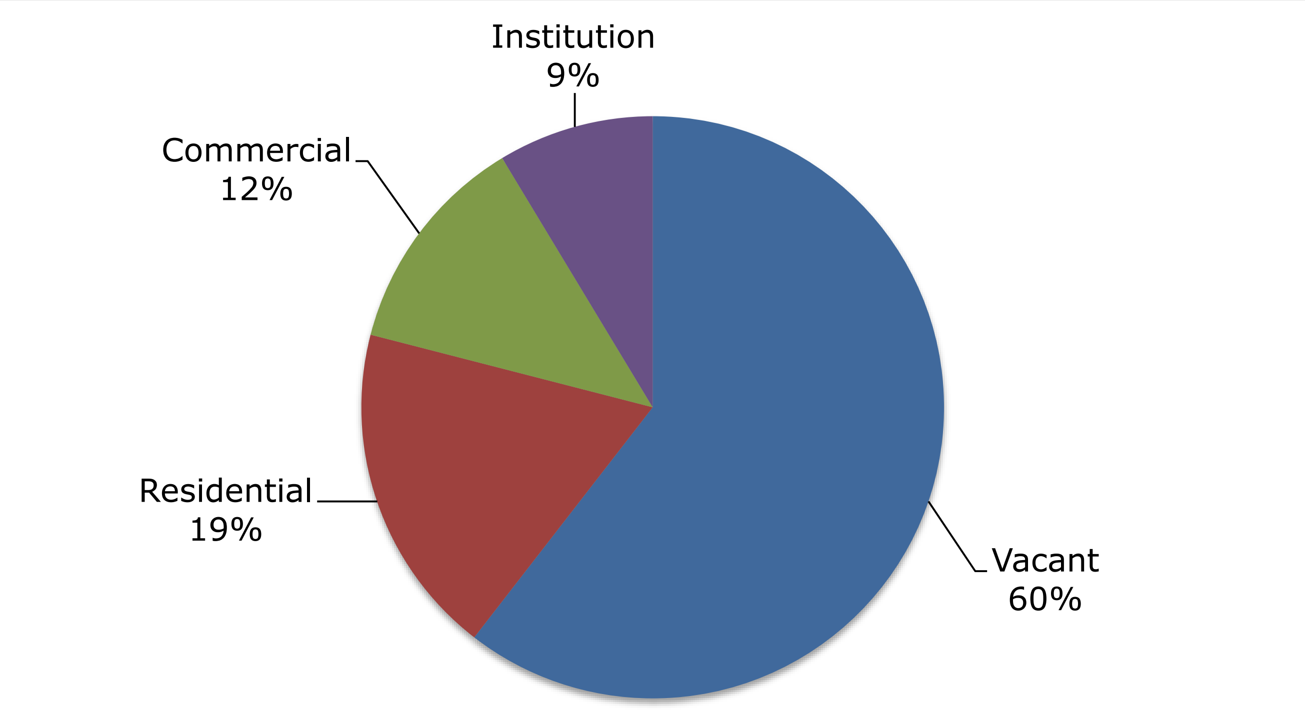


Types of ground cover encountered in Powys. Bold labels denote permeable surfaces, the remainder are non-permeable.

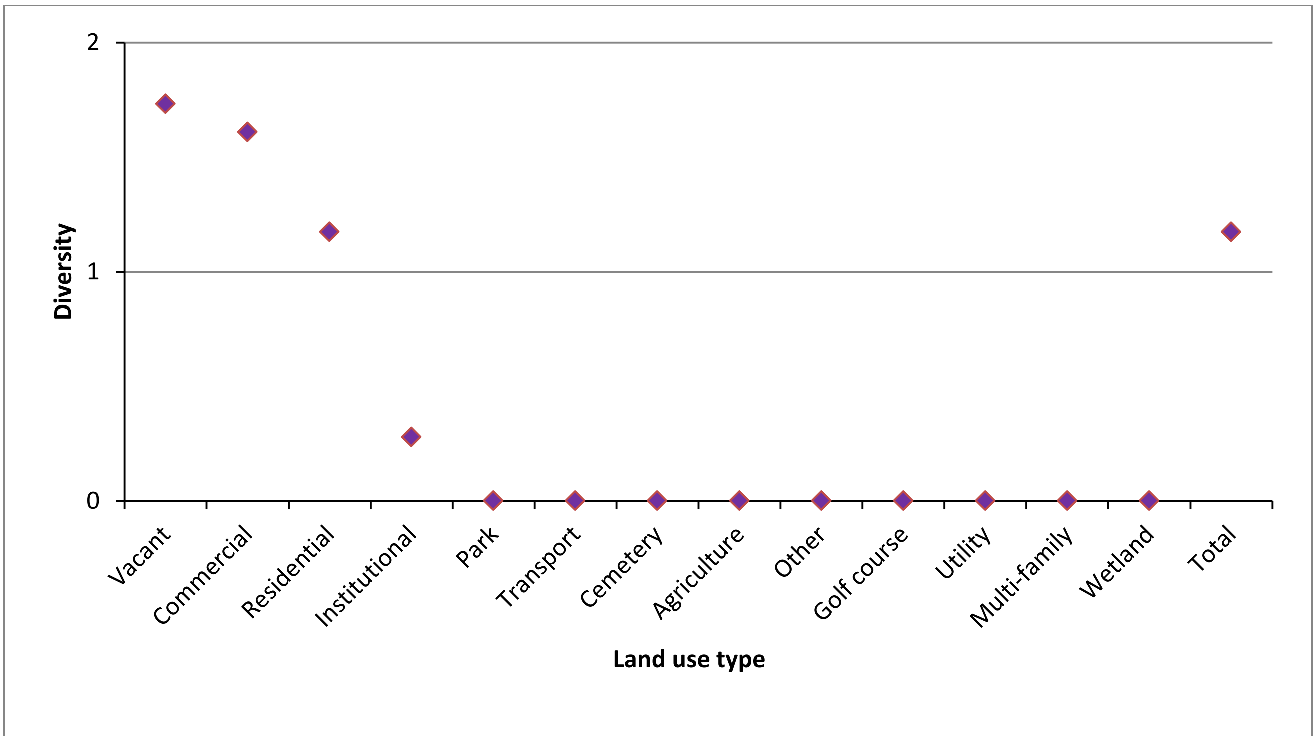
Urban forest structure



Breakdown of trees species in Powys.



Land use types on which trees were present. Land use types where no trees were found are omitted.

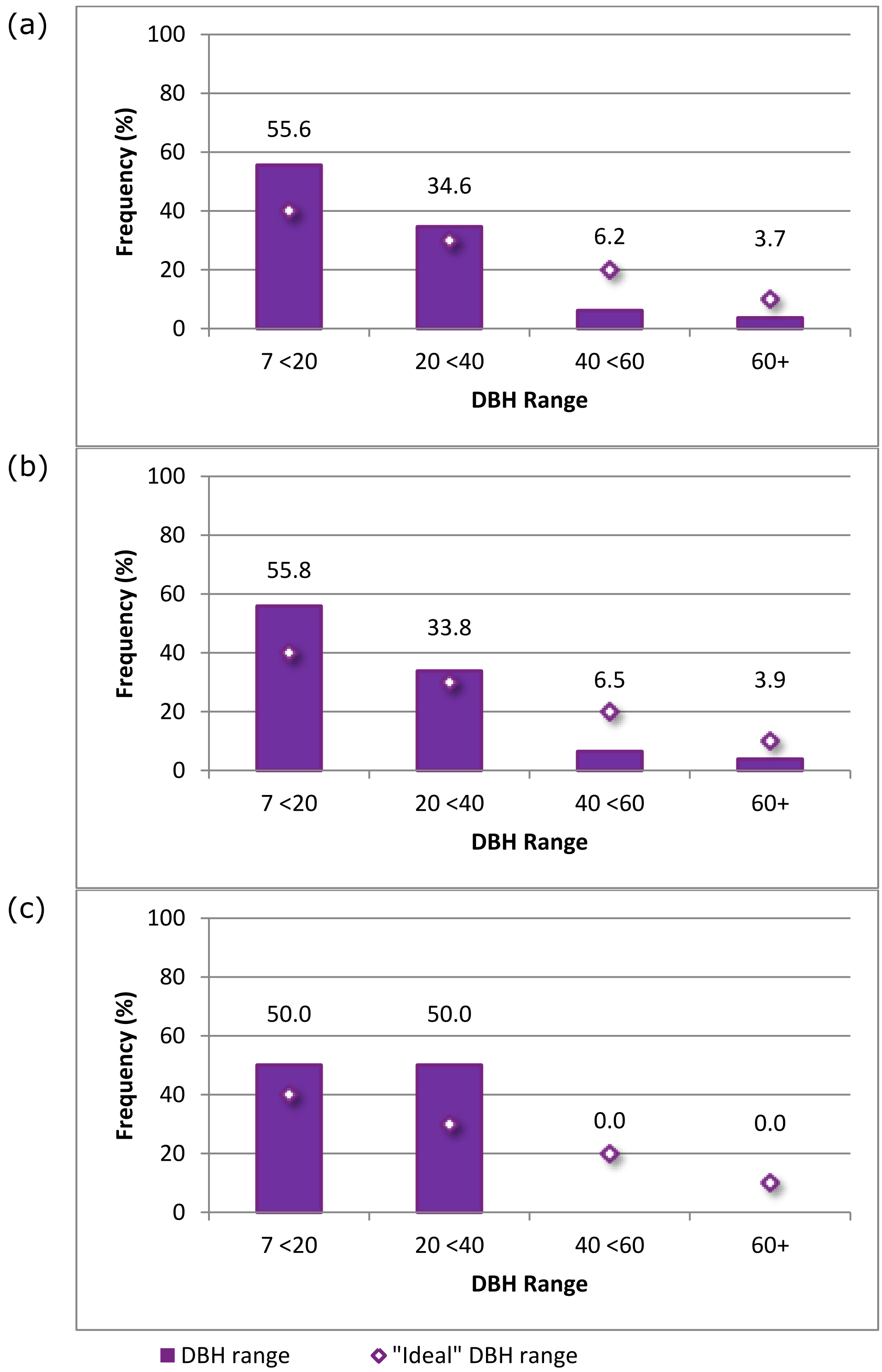


Shannon wiener diversity index values for trees on different land use types in Powys.

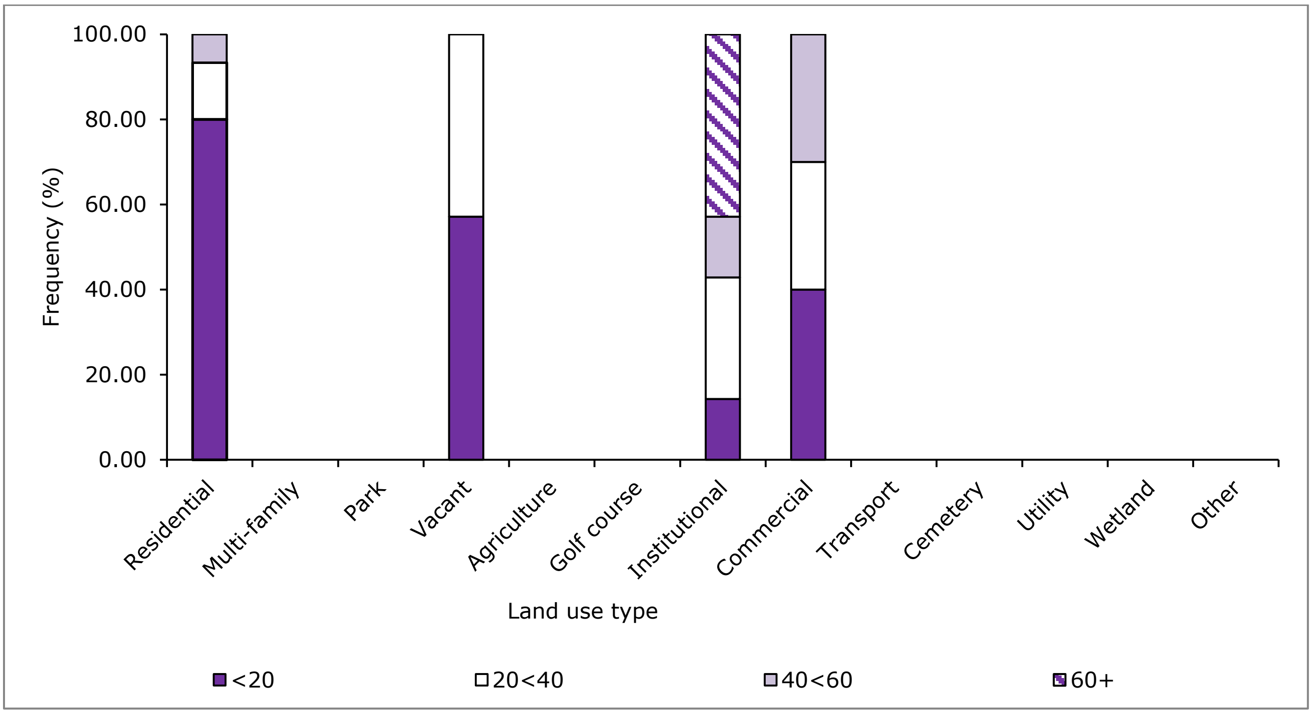
Top three frequency tree species, genus and family.

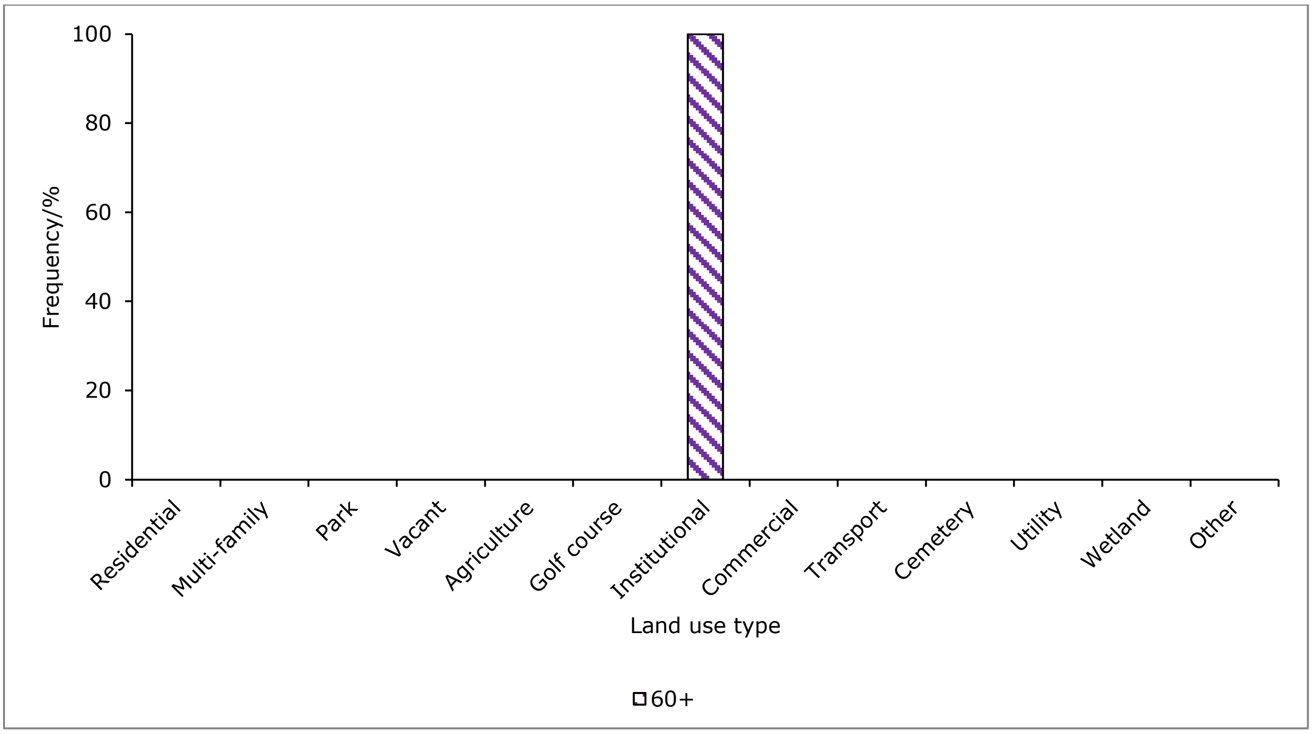
Species	Downy Birch	**18.5 %**	English Oak	**14.8 %**	Sessile Oak	9.5%
Genus	Quercus	28.4 %	Betula	21.0 %	Cupressocyparis	13.6 %
Family	Fagaceae	32.1 %	Betulaceae	25.9 %	Cupressaceae	13.6 %

Bold entries denote groups exceeding the guidelines outlined by Santamour (1990) of no. species exceeding 10%, no. genus 20% and no. family 30%



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





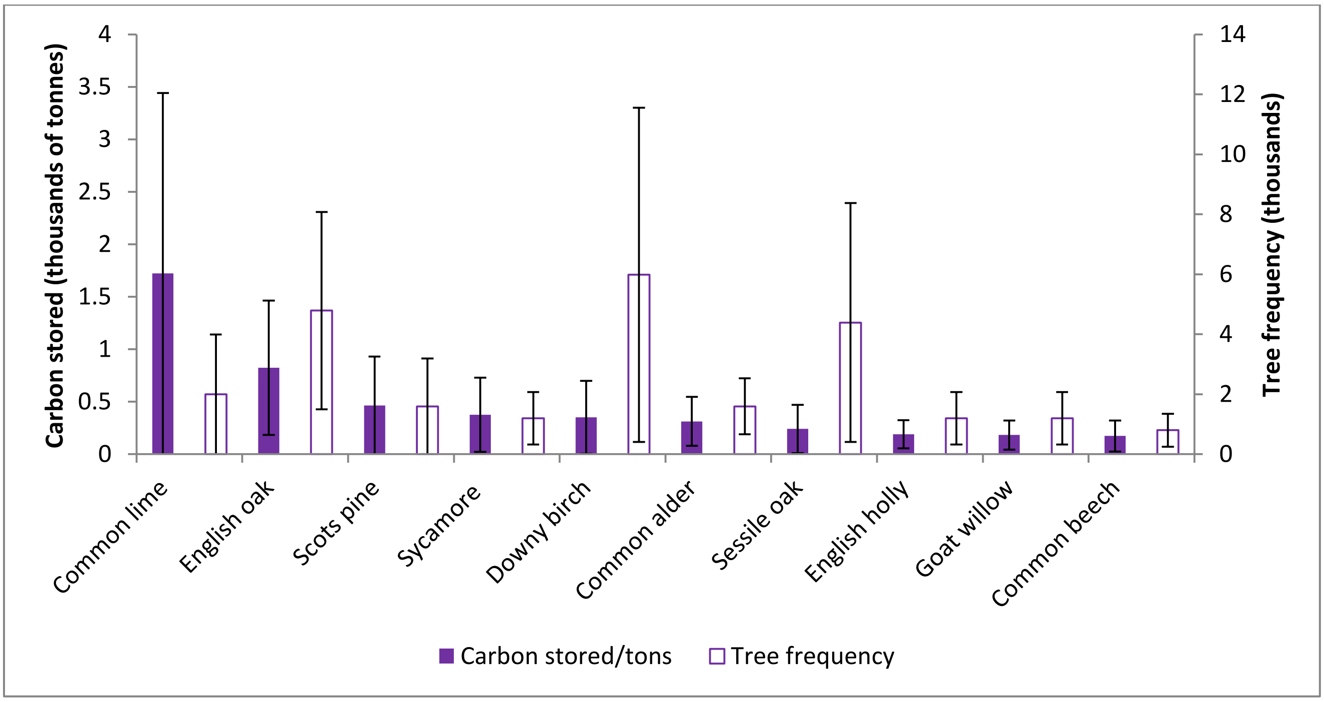
Proportion of diameter size classes per land use type for (a) all DBH size classes and (b) 60cm+ DBH only. A blank denotes land use types where no trees were found.

Ecosystem Services

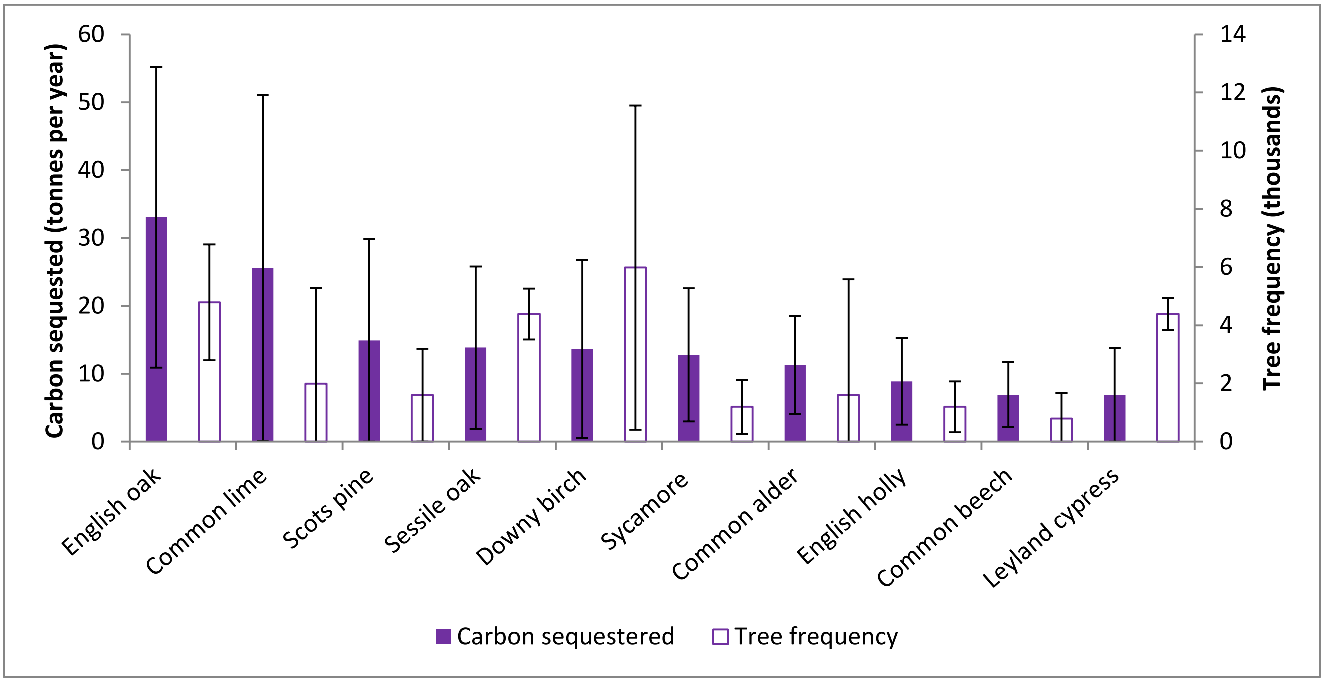
Avoided Runoff for Trees in Powys by Land Use

Land Use	Powys	Tawe catchment
Number of trees	32,316	535,458
Leaf area (km^2)	3.9	48
Avoided runoff (litres / yr)	20,220,000	252,200,000
Avoided runoff Value (£)	26,767	333,865

Rain avoided runoff is calculated by the price £1.3238 m^{-3}



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



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

It is estimated that trees in Powys' urban forest store a total of 5,140 tonnes of carbon in their wood. Based on the central scenario for non-traded carbon, this carbon is currently worth an estimated £1.17 million; and is forecast to be worth £2.64 million in 2050. These values are based on the UK government's non-traded carbon valuation method and assume that the structure of the urban forest remains unchanged between now and 2050.The net amount of carbon sequestered by these trees is 165 tonnes per year; estimated to be worth £36,700.

Appendix V - Species Importance List

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

Rank	Species	Population (%)	Leaf Area (%)	Importance Value
1	Common alder	13.20	5.57	18.77
2	Goat willow	9.91	8.10	18.01
3	Sycamore	4.89	12.86	17.75
4	Common ash	6.78	9.05	15.83
5	English oak	5.50	8.49	13.99
6	Downy birch	7.37	2.77	10.14
7	Sessile oak	3.77	4.93	8.70
8	Common lime	0.84	6.08	6.91
9	Field maple	3.11	3.12	6.23
10	Silver birch	2.46	2.19	4.64
11	White poplar	2.80	1.76	4.56
12	Small-leaved lime	0.78	3.30	4.07
13	Leyland cypress	3.07	0.94	4.01
14	Common beech	0.37	3.48	3.85
15	English holly	2.52	1.30	3.82
16	Scotch pine	1.61	1.90	3.51
17	Lodgepole pine	2.49	0.92	3.41
18	Common hawthorn	2.15	0.85	2.99
19	Plum spp	1.79	0.83	2.61
20	European aspen	1.71	0.79	2.50
21	Austrian pine	1.87	0.39	2.26
22	Grey alder	1.40	0.49	1.89
23	Common plum	1.40	0.49	1.89
24	Norway maple	0.31	1.54	1.85
25	Weeping willow	0.47	1.37	1.84
26	European mountain ash	1.07	0.67	1.75
27	Laurel bay	0.78	0.97	1.75
28	White willow	1.24	0.48	1.73
29	Lawson's Cypress	0.93	0.78	1.71
30	Birch spp	0.22	1.36	1.58
31	Hazel	0.84	0.65	1.49
32	Magnolia spp	0.93	0.49	1.43
33	Wych elm	0.31	1.05	1.36
34	Common apple	1.00	0.25	1.25
35	English yew	0.22	0.92	1.14
36	Engelmann spruce	0.16	0.84	1.00
37	Western Balsam Poplar	0.16	0.77	0.92
38	Monterey cypress	0.16	0.72	0.88
39	Magnolia bark	0.62	0.23	0.85
40	Alder spp	0.47	0.37	0.84
41	Organ oak	0.47	0.29	0.76
42	Cypress spp	0.31	0.37	0.69

43	Eucalyptus spp	0.31	0.37	0.68
44	Mountain ash spp	0.16	0.49	0.65
45	Copper beech	0.16	0.44	0.59
46	Balsam poplar	0.47	0.12	0.59
47	European black Elderberry	0.31	0.28	0.59
48	Maple spp	0.16	0.37	0.53
49	Sweetgum	0.31	0.17	0.48
50	Large gray willow	0.35	0.11	0.46
51	Spruce spp	0.31	0.09	0.40
52	Western hemlock	0.07	0.32	0.40
53	European larch	0.07	0.30	0.38
54	Corsican pine	0.31	0.05	0.36
55	Kwanzan cherry	0.22	0.13	0.35
56	Korean mountain ash	0.16	0.19	0.34
57	Whitebeam	0.16	0.18	0.33
58	Tibetan cherry	0.16	0.16	0.32
59	Beech spp	0.07	0.23	0.30
60	Black cherry	0.16	0.12	0.28
61	Glossy privet	0.16	0.12	0.27
62	Smooth-leaf elm	0.16	0.11	0.26
63	European hornbeam	0.13	0.12	0.25
64	Tawhiwhi	0.16	0.09	0.24
65	Rhododendron spp	0.22	0.01	0.23
66	English elm	0.16	0.08	0.23
67	Japanese maple	0.16	0.07	0.22
68	Sitka spruce	0.16	0.07	0.22
69	Western red cedar	0.13	0.07	0.20
70	Box elder	0.16	0.04	0.20
71	Lilac spp	0.16	0.04	0.19
72	Prunus	0.16	0.03	0.19
73	Common cherry laurel	0.16	0.03	0.19
74	Mahonia spp	0.16	0.02	0.17
75	Red cedar spp	0.16	0.01	0.17
76	Mexican alder	0.16	0.01	0.16
77	Oak spp	0.16	0.00	0.16
78	Willow spp	0.16	0.00	0.16
79	Wild cherry	0.16	0.00	0.16
80	Apple spp	0.16	0.00	0.16
81	'Nymansay' eucryphia	0.07	0.07	0.13
82	Fraser photinia	0.07	0.07	0.13
83	Lacebark	0.07	0.05	0.11
84	Golden ash	0.07	0.05	0.11
85	Saucer magnolia	0.07	0.03	0.10
86	Pear spp	0.07	0.00	0.08
87	Hawthorn spp	0.07	0.01	0.08
88	Zygia spp	0.07	0.00	0.07

Appendix VI. Non-traded values for carbon stored in the Tawe catchment's trees in all three valuation scenarios.

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

						Non-traded unit value (£/tCO2e)					Value of discounted stored (£/tCO2e)		
	Year	Stored C (t)	Net sequestered C (t)	Stored C (tCO2e)	Net sequestered C (tCO2e)	Low	Central	High	Discount rate	Discount factor	Low	Central	High
1	2015	101,252	3,015	371,257	11,054	30	60	90	3.5	1.00	11,532,125	23,064,249	34,596,374
2	2016	104,267	3,015	382,311	11,054	30	61	91	3.5	0.97	11,630,956	23,261,911	34,892,867
3	2017	107,281	3,015	393,365	11,054	31	62	93	3.5	0.93	11,720,871	23,441,743	35,162,614
4	2018	110,296	3,015	404,419	11,054	31	63	94	3.5	0.90	11,802,196	23,604,392	35,406,589
5	2019	113,311	3,015	415,473	11,054	32	64	95	3.5	0.87	11,875,245	23,750,490	35,625,735
6	2020	116,325	3,015	426,527	11,054	32	65	97	3.5	0.84	11,940,323	23,880,646	35,820,969
7	2021	119,340	3,015	437,581	11,054	33	66	98	3.5	0.81	12,017,428	24,034,855	36,052,283
8	2022	122,355	3,015	448,635	11,054	33	67	100	3.5	0.78	12,084,094	24,168,188	36,252,282
9	2023	125,370	3,015	459,688	11,054	34	68	102	3.5	0.75	12,140,623	24,281,246	36,421,869
10	2024	128,384	3,015	470,742	11,054	34	69	103	3.5	0.73	12,187,318	24,374,637	36,561,955
11	2025	131,399	3,015	481,796	11,054	35	70	105	3.5	0.70	12,224,487	24,448,974	36,673,461
12	2026	134,414	3,015	492,850	11,054	36	71	107	3.5	0.68	12,252,437	24,504,875	36,757,312
13	2027	137,428	3,015	503,904	11,054	36	72	108	3.5	0.65	12,271,478	24,542,956	36,814,434
14	2028	140,443	3,015	514,958	11,054	37	73	110	3.5	0.63	12,281,917	24,563,835	36,845,752
15	2029	143,458	3,015	526,012	11,054	37	74	112	3.5	0.61	12,284,064	24,568,127	36,852,191
16	2030	146,473	3,015	537,066	11,054	38	75	113	3.5	0.59	12,278,223	24,556,446	36,834,669
17	2031	149,487	3,015	548,120	11,054	38	77	115	3.5	0.57	13,214,782	26,429,564	39,644,345

18	2032	152,502	3,015	559,174	11,054	39	78	116	3.5	0.55	14,114,374	28,228,749	42,343,123
19	2033	155,517	3,015	570,228	11,054	42	85	127	3.5	0.53	14,976,914	29,953,828	44,930,742
20	2034	158,531	3,015	581,282	11,054	46	92	138	3.5	0.51	15,802,418	31,604,837	47,407,255
21	2035	161,546	3,015	592,336	11,054	50	99	149	3.5	0.49	16,591,001	33,182,003	49,773,004
22	2036	164,561	3,015	603,390	11,054	53	107	160	3.5	0.47	17,342,864	34,685,728	52,028,592
23	2037	167,576	3,015	614,444	11,054	57	114	171	3.5	0.46	18,058,286	36,116,572	54,174,858
24	2038	170,590	3,015	625,498	11,054	60	121	181	3.5	0.44	18,737,619	37,475,239	56,212,858
25	2039	173,605	3,015	636,551	11,054	64	128	192	3.5	0.43	19,381,281	38,762,562	58,143,842
26	2040	176,620	3,015	647,605	11,054	68	135	203	3.5	0.41	19,989,745	39,979,490	59,969,235
27	2041	179,634	3,015	658,659	11,054	71	143	214	3.5	0.40	20,563,538	41,127,077	61,690,615
28	2042	182,649	3,015	669,713	11,054	75	150	225	3.5	0.38	21,103,235	42,206,470	63,309,705
29	2043	185,664	3,015	680,767	11,054	78	157	235	3.5	0.37	21,609,449	43,218,898	64,828,347
30	2044	188,678	3,015	691,821	11,054	82	164	246	3.5	0.36	22,082,831	44,165,662	66,248,492
31	2045	191,693	3,015	702,875	11,054	86	171	257	3.5	0.35	22,640,768	45,281,536	67,922,303
32	2046	194,708	3,015	713,929	11,054	89	179	268	3.5	0.33	23,172,127	46,344,254	69,516,381
33	2047	197,723	3,015	724,983	11,054	93	186	279	3.5	0.32	23,677,197	47,354,394	71,031,592
34	2048	200,737	3,015	736,037	11,054	97	193	290	3.5	0.32	24,156,299	48,312,598	72,468,897
35	2049	203,752	3,015	747,091	11,054	100	200	300	3.5	0.31	24,609,780	49,219,560	73,829,339
36	2050	206,767	3,015	758,145	11,054	104	207	311	3.5	0.30	25,038,013	50,076,026	75,114,039
37	2051	209,781	3,015	769,199	11,054	107	215	322	3.5	0.29	25,540,479	50,858,867	76,399,347
38	2052	212,796	3,015	780,253	11,054	111	222	333	3.5	0.28	26,003,970	51,570,898	77,574,868

Calculation notes: the total amount of carbon stored and the annual sequestration rates are calculated to a baseline year of 2015.

Appendix VII – Pests and Diseases

Acute Oak Decline

Acute oak decline (AOD) affects mature trees (>50 years old) of both native oak species (common oak and sessile oak). Over the past four years, the reported incidents of stem bleeding, a potential symptom of AOD, have been increasing. The incidence of AOD in Britain is un-quantified at this stage but estimates put the figure at a few thousand affected trees. The condition seems to be most prevalent in the Midlands and the South East of England as far west as Wales. There are confirmed cases on the Welsh/English border. Acute Oak Decline poses a threat to 9.4% of the Tawe catchment's urban forest.

Asian Longhorn Beetle

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

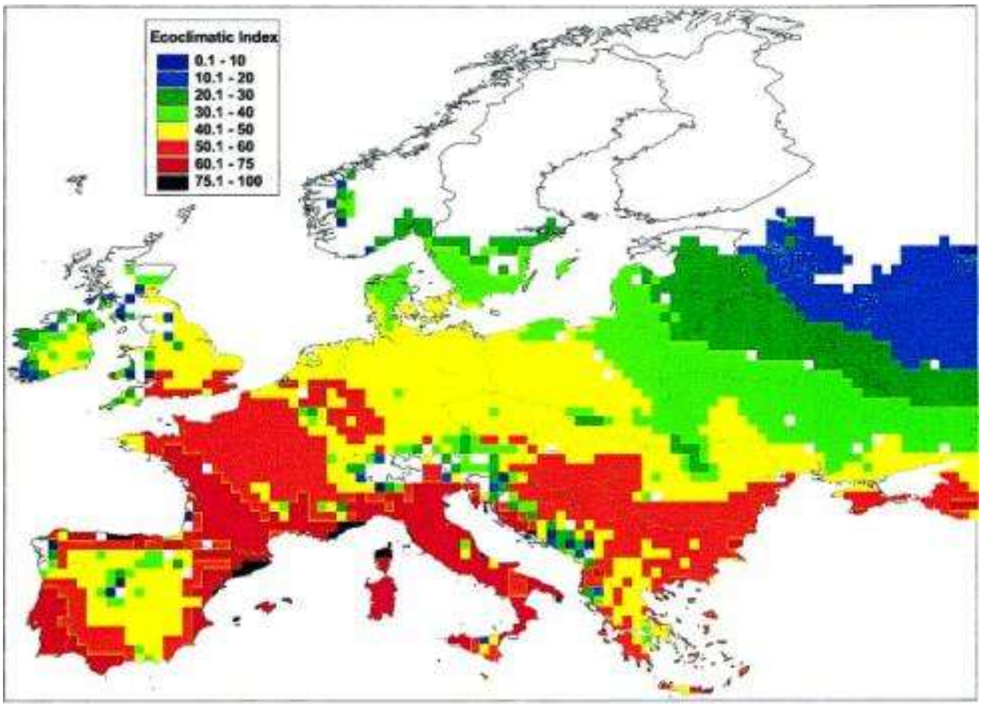


Figure 21. Ecoclimatic Indices for countries across Europe. An index of >32 is suggested to be suitable for ALB (Ref: MacLeod *et al.,* 2002).

In March 2012 an ALB outbreak was found in Maidstone, Kent. The Forestry Commission and Fera removed more than 2, 000 trees from the area to contain the outbreak. No further outbreaks have been reported in the UK. Analysis of climate data suggests that most of Wales and England and some warmer coastal areas of Scotland are suitable for beetle establishment, but south-east England and the south coast are at greatest risk.

MacLeod, Evans & Baker (2002) modelled climatic suitability for outbreaks based on outbreak data from China and the USA and suggested that CLIMEX (the model used) Ecoclimatic Indices of >32 could be suitable habitats for ALB. Figure 21 suggests that the Tawe catchment may be vulnerable to ALB under this model.

If an ALB outbreak did occur in the Tawe catchment it would pose a significant threat to 65.5% of the trees, not including attacks on shrub species

The known host tree and shrub species include:

Acer spp. (maples and sycamores)

Aesculus spp. (horse chestnut)

Albizia spp. (Mimosa, silk tree)

Alnus spp. (alder)

Betula spp. (birch)

Carpinus spp. (hornbeam)

Cercidiphyllum japonicum (Katsura tree)

Corylus spp. (hazel)

Fagus spp. (beech)

Fraxinus spp. (ash)

Koelreuteria paniculata

Platanus spp. (plane)

Populus spp. (poplar)

Prunus spp. (cherry, plum)

Robinia pseudoacacia (false acacia/black locust)

Salix spp. (willow, sallow)

Sophora spp. (Pagoda tree)

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

Quercus palustris (American pin oak)

Quercus rubra (North American red oak)

Ulmus spp. (elm)

Chalara Dieback of Ash

Ash dieback, caused by the fungus *Chalara fraxinea*, targets common and narrow leaved ash. Young trees are particularly vulnerable and can be killed within one growing season of symptoms becoming visible. Older trees take longer to succumb, but can die from the infection after several seasons. *C. fraxinea* was first recorded in the UK in 2012 in Buckinghamshire and has now been reported across the UK, including in urban areas. Wales has nine confirmed cases of the disease. Ash dieback poses a threat to 6.8% of the Tawe catchment's urban forest.

Emerald Ash Borer

There is no evidence to date that emerald ash borer (EAB) is present in the UK, but the increase in global movement of imported wood and wood packaging poses a significant risk of its accidental introduction. EAB is present in Russia and is moving West and South at a rate of 30-40km per year, perhaps aided by vehicles (Straw et al. 2013). EAB has had a devastating effect in the USA due to its accidental introduction and could add to pressures already imposed on ash trees from diseases such as Chalara dieback of ash.

Emerald Ash borer poses a potential future threat to 6.8% of the Tawe catchment's urban forest.

Giant Polypore

Giant polypore (*Meripilus giganteus*) is a fungus that can cause internal decay in trees without any external symptoms (Schmidt 2006), causing trees to potentially topple or collapse (Adlam 2014). It is particularly common in urban areas and can also cause defoliation and crown dieback (Schmidt 2006; Adlam 2014). Giant polypore predominantly affects hardwoods such as horse chestnut, beech, cherry, mountain ash and oak. 16.3% of the Tawe catchment's urban forest could be vulnerable to giant polypore.

Gypsy Moth

Gypsy moth (GM), *Lymantria dispar*, is an important defoliator of a very wide range of trees and shrubs in mainland Europe, where it periodically reaches outbreak numbers. It can cause tree death if successive, serious defoliation occurs on a single tree. A small colony has persisted in northeast London since 1995 and a second breeding colony was found in Aylesbury, Buckinghamshire in the summer of 2005. Aside from these disparate colonies, GMs range in Europe does not reach as far 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 Waloes, it would pose a threat to 22.7% of the Tawe catchment's urban trees.

Oak Processionary Moth

Established breeding populations of oak processionary moth (OPM) have been found in South and South West London and in Berkshire. It is thought that OPM has been spread on nursery trees. The outbreak in London is now beyond eradicating, whereas efforts to stop the spread out of London and to remove those in Berkshire are underway. The caterpillars cause serious defoliation of oak trees, their principal host, but the trees will recover and leaf the following year. On the continent, they have also been associated with hornbeam, hazel, beech, sweet chestnut and birch, but usually only where there is heavy infestation of nearby oak trees. The caterpillars have urticating (irritating) hairs that carry a toxin that can be blown in the wind and cause serious irritation to the skin, eyes and bronchial tubes of humans and animals. They are considered a significant human health problem when populations reach outbreak proportions, such as those in The Netherlands and Belgium have done in recent years. Oak processionary moth poses a threat to 13.5% of the Tawe catchment's urban forest.

Phytophthora ramorum

Phytophthora ramorum was first found in the UK in 2002 and primarily affects species of oak (Turkey oak, Red oak and Holm oak), beech and sweet chestnut. However, it has also been known to occasionally infect European and hybrid larch and kills Japanese larch. Rhododendron is a major host, which aids the spread of the disease. In 2010 it was found on larch trees in South Wales. Many cases have been identified in Wales and in particular S. Wales. *Phytophthora ramorum* poses a threat to 0.6% of the Tawe catchment's urban forest.

Phytophthora kernoviae

Phytophthora kernoviae (PK) was first discovered in Cornwall in 2003. The disease primarily infects rhododendron and bilberry (*Vaccinium*) and can cause lethal stem cankers on beech. PK has been found at five locations in South Wales. The Welsh outbreaks have largely been contained at four of the sites, and in the fifth, a private garden, there was one infected plant, which was removed and destroyed. *Phytophthora kernoviae* is deemed to pose a risk to 8.6% of the Tawe catchment's urban forest and also affects many of the shrub species identified in the survey.

Phytophthora alni

Phytophthora alni affects all alder species in Britain which was first discovered in the country in 1993. Phytophthora disease of alder is now widespread in the riparian ecosystems in the UK where alder commonly grows. On average, the disease incidence is highest is southeast England. However, heavy losses are occurring in some of the large alder populations that occur along western rivers for example, in the Marches and parts of Wales. *Phytophthora alni* poses a threat to 15.2% of the Tawe catchment's urban forest.

Dothistroma needle blight

Dothistroma (red band) needle blight is the most significant disease of coniferous trees in the North of the UK. The disease causes premature needle defoliation, resulting in loss of yield and, in severe cases, tree death. It is now found in many forests growing susceptible pine species, with Corsican, lodgepole and, more recently, Scots pine all being affected. The disease has been found in three out of the four Natural Resources Wales' land management areas. While there are no reported cases of red band needle blight on urban trees 6.3% of the Tawe catchment's urban forest is potentially at threat from it.

Great Spruce Bark Beetle

The great spruce bark beetle (*Dendroctonus micans*) damages spruce trees by tunnelling into the bark of the living trees to lay its eggs under the bark, and the developing larvae feed on the inner woody layers. This weakens, and in some cases can kill, the tree. It has become an established pest in Wales. The great spruce bark beetle poses a threat to 0.5% of the Tawe catchment's urban forest.

Glossary of Terms

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

Broadleaf species – for example, alder, ash, beech, birch, cherry, elm, hornbeam, oak, 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 part of a plant that is the totality of the plant's above-ground parts, including stems, leaves, and reproductive structures

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

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

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

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

Ecosystem services - benefits people obtain from ecosystems

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

Leaf area index - the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows

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

Meteorological - phenomena of the atmosphere or weather

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

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

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

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

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

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

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

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

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

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

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

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