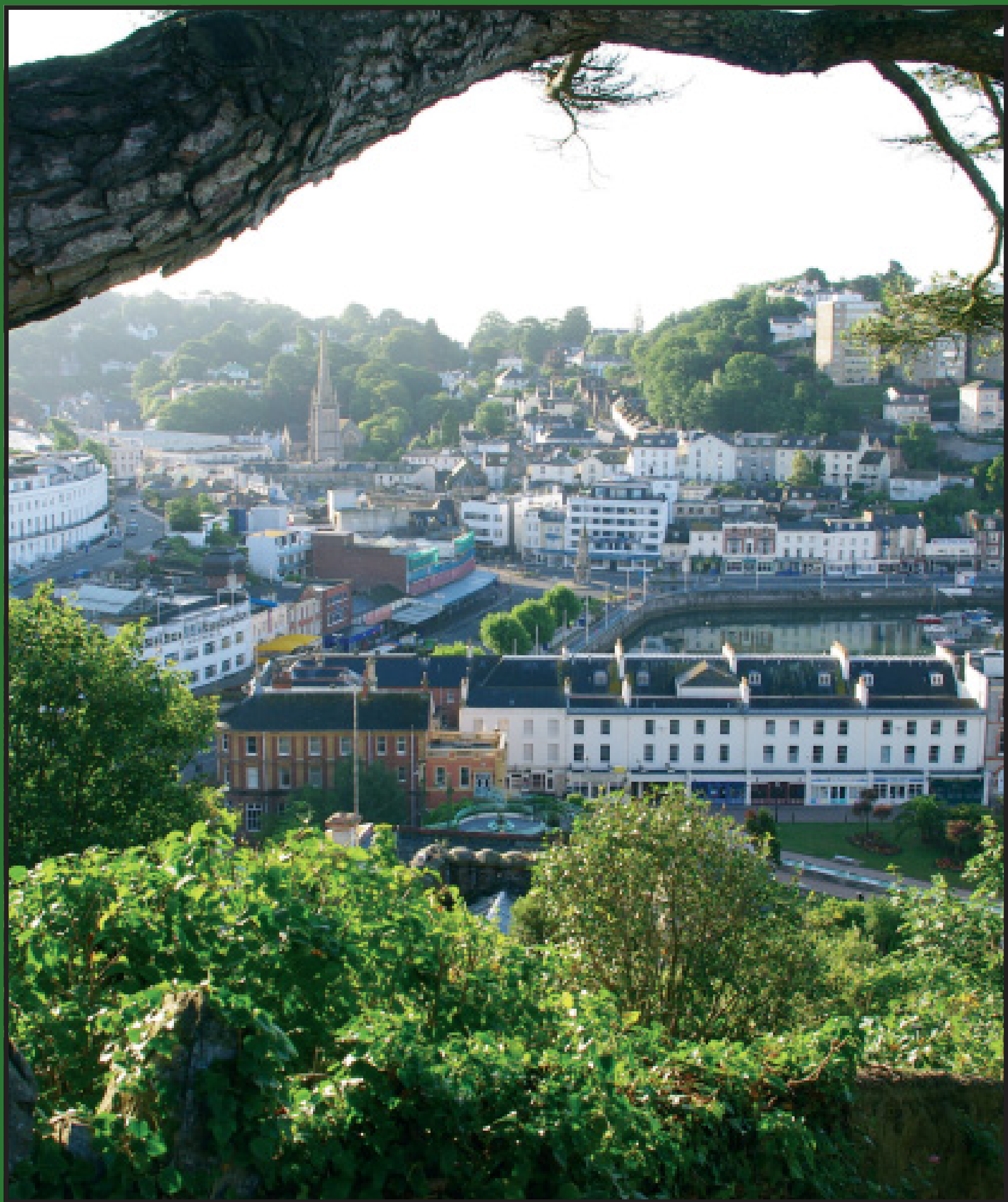
Torbay's Urban Forest

Assessing Urban Forest Effects and Values

A report on the findings from the UK i-Tree Eco pilot project



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Foreword

Few doubt the importance of trees or that they are intrinsically linked to our health and well-being. Nowhere is this more apparent than in our cities. Over half the worlds population now live in urban areas and because of this the urban forest plays a crucial role in the ecology of human habitats. Trees and green spaces make our towns and cities better places to live.

Trees filter pollutants from the air, provide habitat for animals and places for people to socialise and exercise. They moderate local climate, cooling our town centres in summer, slowing wind and storm-water run-off. The shade of trees and their beauty creates and frames spaces for people to meet and play. Trees and shrubs connect us to nature, provide roosts and food for birds and habitat for other animals.

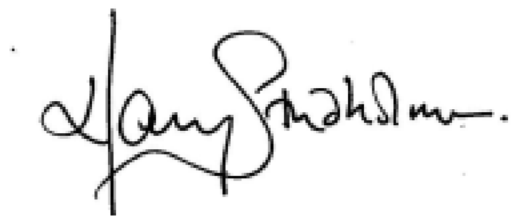
Where there are trees and green spaces businesses flourish, people linger and shop longer, apartments and office space rent quicker, tenants stay longer, property values increase, and new business and industry is attracted. The physical effects of trees—the shade (solar regulation), humidity control, wind control, erosion control, evaporative cooling, sound and visual screening, traffic control, pollution absorption and precipitation—all have economic benefits.

The Millennium Ecosystem Assessment has put values to the economic benefits of our natural environment demonstrating how society has undervalued the services provided by nature. Perhaps because we have not adequately appreciated this value over the last 50 years we have degraded two thirds of our planets ecosystems. With this impact ever more visible and with a changing climate it is more important than ever to understand the structure and value of our natural capital, so that we can plan for sustainable and prosperous places to live and work.

This study represents a new way to analyse the Urban Forest and respond to the increased regulatory focus on the value of ecosystem services. By placing a value on the benefits to society of the urban forest the importance of this resource can be made tangible to policy makers, communities and businesses.

With better information (including economic understanding) we can make better long term decisions to maintain and improve the urban environment for the benefit of current and future populations of Torbay. Leading by example Torbay's experience shows a way forward for other towns and cities in this country.

Sir Harry Studholme



GB Forestry Commissioner

The Authors

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INTERNATIONAL YEAR OF FORESTS • 2011

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Neil Coish
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Andy Brunt
Project Leader, Forest Research

Project steering group members, who have assisted with the project and final report, including:

Tony Hutchings	Forest Research
Simon Bates	Climate Change Project Officer, Natural England
Neville Fay	Principal Consultant, Treeworks Environmental Practice
Tim Sunderland	Environmental Economist, Natural England
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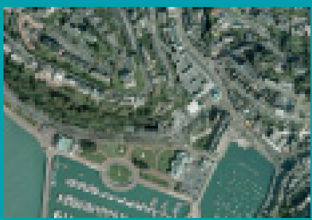
Tim Jarratt

Torbay's urban forest covers 11.8% of theland area. This is slightly above the 11.2% average for the South West, revealed in the 2008 Trees in Towns II study.



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Benefits from the urban forest include:

- Air pollution removal.
- Air temperature reduction.
- Reduced building energy use.
- Absorption of ultraviolet radiation.
- Improved water quality.
- Reduced noise.
- Increased property values.
- Improved psychological well-being.
- Aesthetics and landscape quality.

Executive Summary

The urban forest has the potential to offer multiple services and environmental benefits to society. Trees, and the functions and services that they offer, such as air quality improvement, carbon sequestration or temperature reduction, are directly influenced by management and actions that affect its structure. Therefore, proper management of urban green spaces can increase the environmental benefits of trees present in the area.

A first step to improve the management of the urban forest is to evaluate its current structure and distribution, obtaining a baseline from which to set goals and to monitor any changes. By measuring the structure of the urban forest (the physical attributes such as species composition, tree density, tree health, leaf area and biomass), the functions (benefits or ecosystem services) of the urban forest can also be calculated and valued.

In order to gain a better understanding of Torbay's urban forest resource a public/private partnership project was formed in 2010 consisting of the Borough of Torbay, Hi-line, Forest Research and Natural England with the aim of collecting the data and presenting the findings.

This project piloted the use of i-Tree Eco model in the UK. Developed by the US Forest service, Eco is used for assessing the structural value and environmental benefits that urban trees provide.[1]

Torbay Urban Forest Summary		
Number of trees	818,000	
Tree cover	11.8%	
Most common species	Leyland cypress, Ash and Sycamore	
Pollution removal	50 tonnes per-year	£281,495 (USEC)
		£1,330,000 (UKSDC)
Carbon storage	98,100 tonnes	£1,474,508 (USEC)
		£5,101,200 (UKSDC)
Carbon sequestration	3320 tonnes (net)	£64,316 (USEC)
		£172,640 (UKSDC)
Structural Value	£280,000,000	
Average stem diameter	11.5cm	

Table 1: Headline Findings
United States Externality Costs (USEC)
United Kingdom Social Damage Costs (UKSDC) for explanation see overleaf

[1] i-Tree Eco: http://www.itreetools.org

US externality and UK social damage costs

The i-Tree Eco model provides figures using US externality and abatement costs. Basically speaking this reflects the cost of what it would take a technology (or machine) to carry out the same function that the trees are performing, such as scrubbing the air or locking up carbon.

For 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, because 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 (DECC, 2009).

This approach gives higher values to 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 affects of climate change (DECC, 2009).

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. Values were taken from the Interdepartmental Group on Costs and Benefits (IGCB) based on (DEFRA, 2007). They are a conservative estimate because they do not include damage to ecosystems; SO2 negatively impacts trees and freshwater and NOx contributes to acidification and eutrophication (DEFRA, 2007). For PM10s, which are the largest element of the air pollution benefit, a range of economic values is available depending on how urban (hence densely populated) the area under consideration is (IGCB).

For both carbon and air pollution removal, the assumption has been made that the benefit to society from a tonne of gas removed is the same as the cost of a tonne of the same gas emitted.

Trees not only provide functional benefits which can be estimated and valued, but also contribute to less tangible benefits such as our general wellbeing and landscape character for example. Trees and natural spaces help create the *Genus loci or 'spirit of the place'.*

Long Quarry Point, Torbay

Tim Jarratt

Introduction

A number of recent Government documents have highlighted the importance of the range of benefits delivered by healthy functioning natural systems:

- The Lawton Report: Making Space for Nature (2010). This report found that too many of the benefits that derive from nature are not properly valued; and that the value of natural capital is not fully captured in the prices customers pay, in the operations of our markets or in the accounts of government or business.

- UK National Ecosystem Assessment (2011), highlighted that a healthy, properly functioning natural environment is the foundation of sustained growth, bringing benefits to communities and businesses.

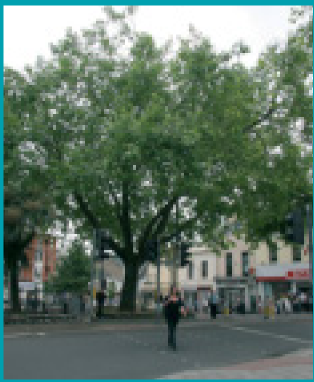
- The Natural Choice: Securing the Value of Nature (2011). This white paper set out an integrated approach for creating a resilient ecological network across England, and supporting healthy, well-functioning ecosystems and ecological networks.

The UK has a long history of trees in urban areas. They range from the ancient tradition of churchyard yews, to trees established by Victorian philanthropists, through to their use in the modern regeneration of post-industrial sites.

These trees provide a range of environmental, economic and social benefits to people in urban areas, including:

- Shade and evaporative cooling.
- Interception and capture of airborne pollutants.
- Interception and storage of rainwater.
- Storage of atmospheric carbon.
- Noise abatement.
- Wildlife habitat.
- Improvement of human health and well-being.

The role of urban trees was (until recently) poorly understood, and their contribution to urban areas often undervalued. We are now able to assess the extent and value of a number of the environmental benefits listed above.


Kenton Rogers

Studies such as that by Wolf (2007) have shown that shoppers stay longer and spend more in leafier environments.

i-Tree Eco was originally developed as the Urban Forest Effects (UFORE) model in the mid-1990s to assess urban forest impacts on air quality. It has since become the leading urban forest benefits assessment package. It's used in over 60 countries across the globe helping urban foresters, communities and businesses to manage the urban forest effectively.

This report describes the results of a study of Torbay's urban trees, carried out in summer 2010 by a partnership consisting of Torbay Borough Council, Hi-line and Forest Research with additional assistance from Natural England and the Forestry Commission.

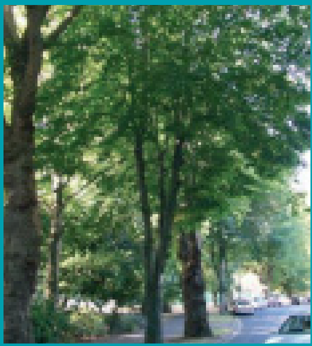
The study (the first of its kind in the UK) used the i-Tree Eco model (developed by the US Forest Service, and based on peer reviewed research) to quantify the structure, and some of the major environmental benefits delivered by Torbay's trees.

Plate 1: Torquay is situated in south west England and comprises of the towns Paignton, Brixham and Torquay. It covers an area of approximately 6375 hectares with a population of around 138,000.

Surveyors visited 241 plots within the Torbay area, recording a wide range of tree and shrub species, their size and condition, and the type of land they were found on. Information from the survey was combined with local weather and pollution data to produce an estimate of the monetary value of a range of environmental services from the local trees.

The main findings of the Torbay survey were:

1. Torbay has around 818, 000 trees, covering 11.8% of its land area.
2. These trees have a structural (or replacement) value of around £280 million.
3. Torbay's trees store around 98, 000 tonnes of carbon per year, and sequester around 3320 tonnes per year.
4. The trees remove around 50 tonnes of particulate air pollution from the local atmosphere each year.



Kenton Rogers

Torbay's urban forest improves air quality by removing over 50 tons of pollutants from the air every year, a service worth at least £ 1.3 million annually.

According to Gerhald and Frank (2002) The benefit of an urban forest is not a new concept and was recognised as far back as the 13th Century with the planting of Elm trees, incorporated into the lawns adjacent to cathedrals.

Work by Natural England suggests that the value of carbon storage and sequestration by Torbay's trees is around £5 million and £0.2 million respectively. Air pollution removal is suggested to be worth around £1.3 million per year.

Information from this survey has also been used to justify an additional investment of £25k into Torbay's tree maintenance budget, arresting a decline seen in recent years.

i-Tree Eco was identified as the most complete tool currently available for analyzing the urban forest, as it is capable of providing the most detailed results on the structure and functions of trees. It is therefore a very useful tool in order to discover, manage, make decisions on and develop a good strategy concerning the trees present in Torbay. The i-Tree Eco model has been used successfully in many towns and cities in over 60 countries throughout the world, but the Torbay project was to be the first to attempt to use the system in the UK.

This report outlines the findings of that study[2]. Our main objectives were to:

• Assess the structure, composition and distribution of Torbay's urban forest.

• Quantify some of the benefits (ecosystem services) of Torbay's trees in order to raise awareness of the value of trees in the urban environment.

• Establish a baseline from which to monitor trends and future progress.

The data resulting from this study has been used with great effect to develop strategies for maintaining and improving Torbay's Urban Forest and to ensure the long term delivery of ecosystem services for the benefit of its residents.

[2] Rogers et al 2011

"Only 19 percent of Local Authorities have an accurate record of the percentage of their district covered by trees and woods".

Trees in Towns II

Maidencombe, North Torbay

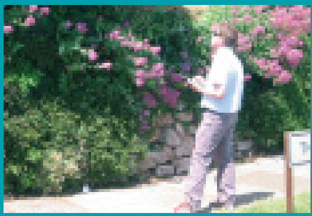
Tim Jarratt

Methodology

To help assess Torbay's urban forest, data from 241 field plots located across the borough were analysed using the i-Tree Eco model. This, combined with a desktop exercise to collect local hourly pollution and meteorological data allowed the project to collect information on the elements described in table 2 below.

Urban Forest Structure and Composition	Species diversity, Tree canopy cover, Age class 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 and PM10. % of total air pollution removed by trees. Current Carbon storage by the urban forest. Carbon sequestered.
Structural and Functional values	Structural values in £. Carbon storage value in £. Carbon sequestration value in £. Pollution removal value in £.
Potential insect and disease impacts	Acute Oak Decline *Phytophthora ramorum* Emerald Ash Borer Asian Longhorn Beetle

Table 2: Study Outputs



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Field Survey Data Collected

Plot Information:

Land use type.

Percent tree cover.

Percent shrub cover.

Percent plantable space.

Percent ground cover type.

Tree information:

Species.

Stem diameter.

Total height.

Height to crown base.

Crown width.

Percent foliage missing.

Percent dieback.

Crown light exposure

The first step basic process used by i-Tree Eco (also known as the urban forest effects model or UFORE) is to calculate the correct number of survey plots needed to give a representative sample of an urban tree population. Survey data from these plots are used to calculate the species and age class structure, biomass and leaf area index (LAI) of the urban forest. This data is then combined with local climate and air pollution data to produce estimates of carbon sequestration and storage, air pollution interception and removal, the monetary value of these ecosystem services, and the structural value of the trees.

The model can also estimate the predicted future benefits of the existing urban forest by applying growth rate calculations to the current stock.

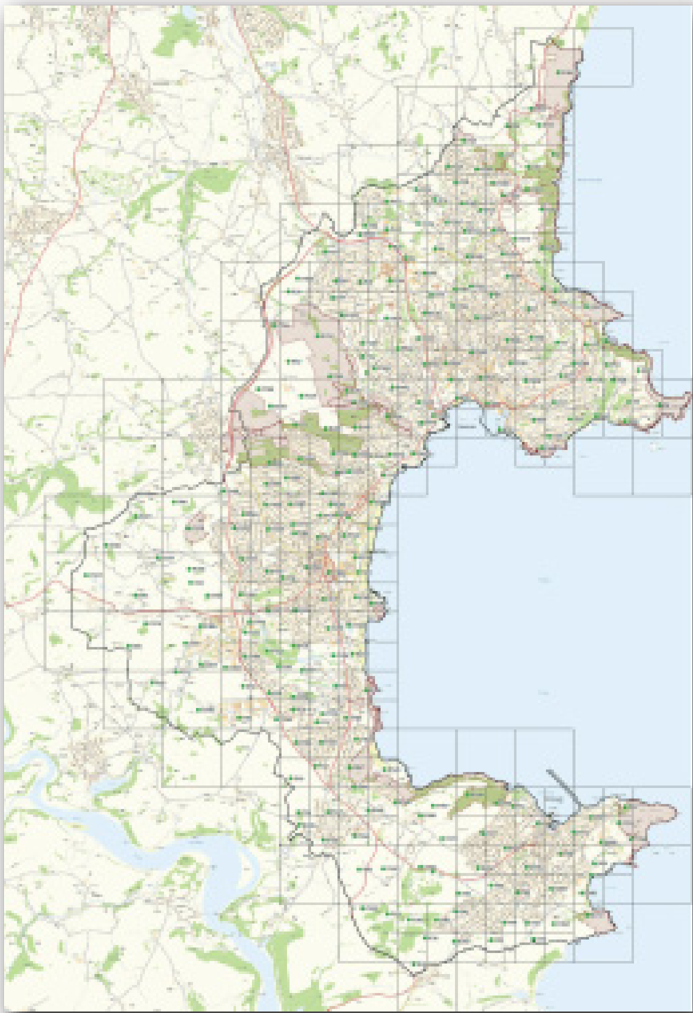


Plate 2: Torbay, divided into 250 grid squares, a sample plot was randomly placed in each square.

Kenton Rogers

Because it is the whole of the urban forest that provides the benefits, plots were situated on both public and private property.

Tim Jarratt

The urban forest includes trees in naturalized areas (top), individuals located in more 'built up' areas (middle) and also open parkland (below).

Tim Jarratt

In practice, the study area of Torbay (defined by its political boundary) was divided into 250 squares (see plate 3) and a randomly placed 0.04 hectare (ha) plot was located within each grid square. This density provided a plot at approximately every 26 ha (yielding a relative standard error of ±10%) . In comparison a similar in Chicago[3] study used 745 plots equating to 1 plot every 80 ha.

Plate 3: Data collection was carried out over the summer months so that tree canopies could be adequately assessed whilst in leaf.

Data was collected on any residential addresses on which a plot was located using GIS. Some plots bordered four or more properties, which in itself posed interesting access and data collection issues. Letters with reply slips were issued to each of these addresses requesting access to the property to carry out the necessary field-work.

The majority of respondents who replied did so positively, allowing 241 of the 250 plots to be measured. Data collection took place during the summer of 2010 to allow for the tree canopies to be properly assessed. 9 of the plots were inaccessible, generally as a result of the terrain encountered, although access to some plots (or part-plots) was denied.

Data collected included information on land-use, ground-cover types, tree species, tree and shrub measurements, composition, condition, and light exposure (see sidebar page 9).

A fuller review of the methodology is provided in the scientific paper on the project published by the Forestry Commission, (see Rogers et al (In Press)). An overview is also provided in Appendix V.

[3] Nowak et al 2010

Land Use and Ground Cover

Land use refers to the main use of the land within each plot.

A large part of Torbay (42%) is classified as residential, and a further 20% is under agriculture. Parks and commercial/industrial areas are also important, at 13% and 12% respectively. Other land uses are represented by lower percentages of cover, with wetland and water particularly low at less than 1% (see fig. 1 below).

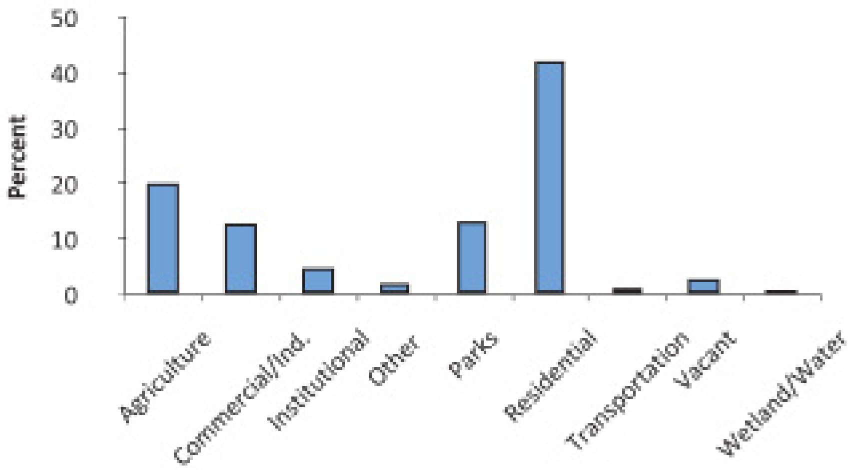


Fig 1: Percentage Land-use

Ground cover refers to the types of ground covering within each plot (for example, a plot located within an industrial may area consist entirely of grass).

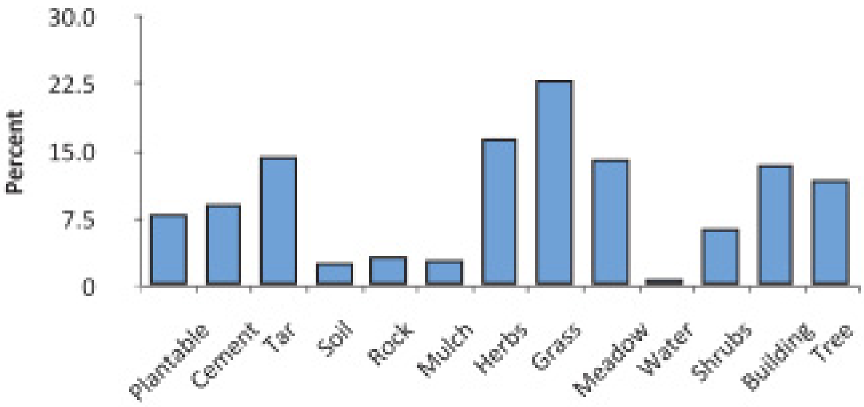


Fig 2: Percentage Ground Cover

Kenton Rogers

40% of Torbay's ground cover is under impervious surfaces such as rock, tar and buildings.

71.1% of Torbay is in private ownership and 28.9% is in the public domain. Trees in Towns II calculated a 66% private and 34% public split as a national average.

11.8% of Torbay is under tree cover. This is slightly higher than the 8.2% average reported for England in Trees and Towns II. A further 6.4% of the land in Torbay is under shrub cover.

Grass (23 %), herbaceous vegetation (16 %), tar (14 %) and buildings (13 %) are the most common ground cover types in Torbay. The relatively large proportions of grass and herbaceous vegetation recorded are likely to be due to the high percentage land use that is occupied by agriculture and gardens.

Currently 11.8 percent of the ground in Torbay is covered by trees. However, although this is lower than estimates for a range European and North American cities (See appendix I), it is slightly higher than the average tree cover in English Cities. Our survey also showed that a further 8% of publicly owned land in the Torbay area could in theory be planted with trees. Additional plantable space may also be available on private property.

Utilizing this space to increase the urban forest cover would potentially help reduce pollution, increase carbon sequestration and reduce energy consumption.

Plate 4: Torquay Harbour, the vegetation amongst the buildings make for a pleasant backdrop to this maritime scene

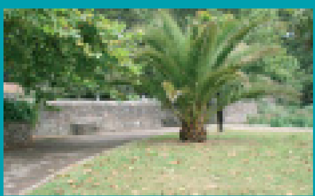
Many international cities have canopy cover goals, recognising the link between increased leaf area, climate adaptation and urban forest sustainability. The formal adoption of tree canopy goals would be crucial in realising any increase in the tree canopy cover.

See Appendix I for a comparison list of urban tree cover in other cities across the world.

Most frequent tree species recorded in the English urban environment compared with those found in Torbay

Species	UK	Torbay
Leyland Cypress	12.3%	14.5%
Hawthorn	6.3%	5.4%
Sycamore	5.7%	10%
Silver Birch	4.6%	0.1%
Ash	4.1%	11.6%
Privet	3.7%	0.2%

UK data from Trees in Towns II



Tim Jarratt

Torbay enjoys a relatively mild climate and Palm trees were one of the top 10 species recorded by population.

Structure of Torbay's Urban Trees

The borough of Torbay has an estimated urban tree population of 818,000 (128 trees per hectare). Tree cover in Torbay is an estimated 11.8 percent of the total area. Of this 71.1 percent of the tree cover is on private land and 28.8 percent is on public land.

The most common tree species found in Torbay are Leyland cypress (118,306 trees, 14.5%), ash (94,776 trees, 11.6%) and sycamore (81,703 trees, 10%), which account for 36.1% of the total population.

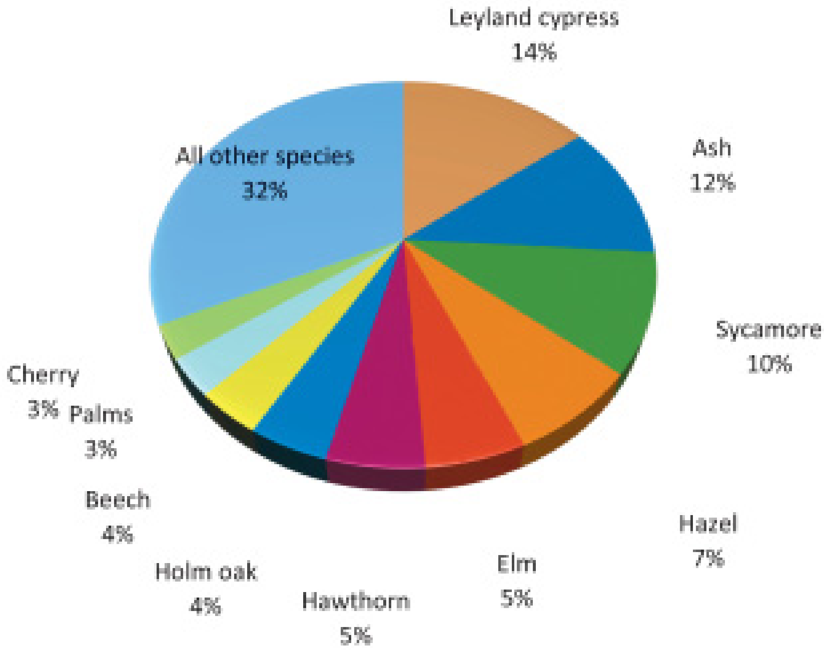
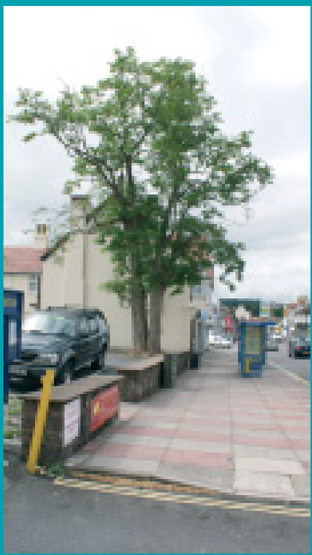


Fig 3: The 10 most common species in Torbay

The ten most common species in Torbay account for 67% of the total population. Urban forests are characterised by a mix of native, naturalised and exotic species that have far higher tree diversity than that of the surrounding landscape. Increased tree diversity has the potential to minimise the impact or destruction by species specific pathogens and diseases.

However, there can be an increased risk to the native tree population by naturalised and exotic species, which can potentially out-compete and displace native species.



Tim Jarratt

False Acacia, Paignton. Although not native to the UK this tree copes well with pollution and poor soils, and is recommended for seaside environments.

Table 3 shows percentages for each of the 6 continents from which the 102 species found in Torbay originate. More than two thirds (68.9%) of the species are of European origin, and of these, 51.4% are native to Britain.

Although North America is the second most important continent of origin at 14.6%, the numbers of tree species from this continent are much lower. The rest of Torbay's species (16.5%) are drawn from all other continents except Antarctica.

Origin	Percent
Europe	68.9
N. America	14.6
Asia	6.8
Australasia	5.8
S. America	2.9
Africa	1.0
% of European species native to Britain	51.4
% of all species native to Britain	35.3

Table 3. Origin of species

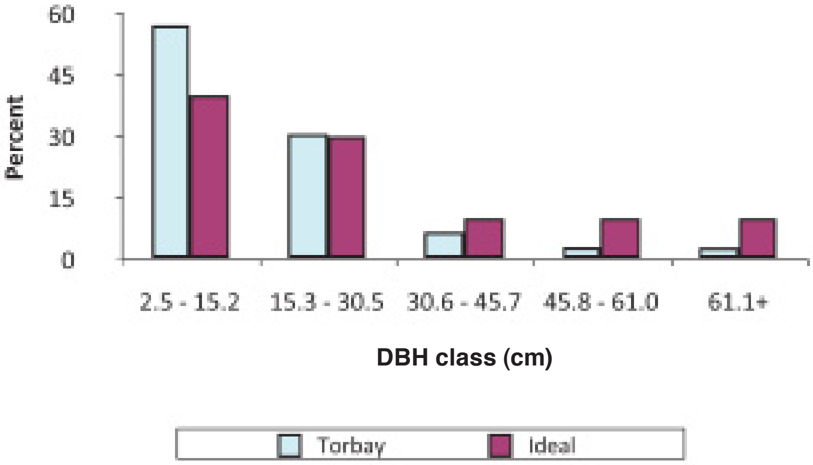
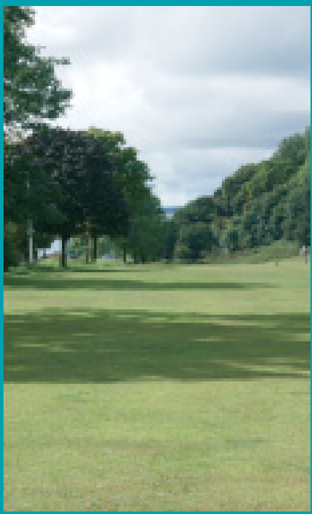


Fig. 5. Diameter at breast height distribution

Figure 5 (above) illustrates the size range of trees within Torbay from their diameters at breast height (dbh). The majority of trees in Torbay (57 percent) are in the lowest size category 2.5cm – 15.2cm DBH, which is higher than the 'ideal' target of 40 percent.

This 'ideal' is based on work by the city of Toronto[4] and is intended as a guideline only. Urban forests are unique and there is no 'one size fits all' target distribution. However, it is noted that Torbay would benefit from a greater proportion of larger trees.

[4] Every Tree Counts - A portrait of Toronto's Urban Forest



Tim Jarratt

Most regions in England only have 10-20% of trees with a dbh that is greater than 30cm (Trees in Towns II). Torbay also falls within this category.

The average dbh of trees in Torbay is 11.4cm. The percentage of trees within each dbh class decrease with increasing diameter class and as a result the percentage of medium and large trees is lower than the ideal scenario illustrated in fig 5.

Torbay has a relatively dense tree population at 128 trees per ha. This can be compared with some US cities (Boston and Chicago have respective densities of 83 and 23 trees per ha), and also to an estimated average for urban areas in the UK of 58.4 trees per ha (Britt & Johnston, 2008). However, overall canopy cover is lower than Boston and Chicago (see appendix I) because the majority of trees in Torbay are smaller than those in Boston and Chicago.

The data shows that only 12.3% of trees in Torbay have a DBH greater than 30.6cm. The high proportion of small trees recorded may be as a result of the following factors:

• Including species in the sample that might normally be classified as shrubs. i-Tree Eco defines a tree as “any woody vegetation that has a DBH greater than 2.5cm in size”. As a result, many Hazel, Leyland Cypress and other common tree and shrub species that are frequently used as hedges were classified as trees. This results in a lower average tree diameter for the entire population.

• The inclusion of small stature species (e.g. fruit trees) that will never achieve large diameters.

• High levels of natural regeneration (self seeded trees) in some of Torbay’s natural wooded areas.

A tree population ideally needs:

- Enough large and mature trees, to deliver the widest possible range of environmental benefits in urban areas.
- Enough trees in a number of younger age classes to replace these mature trees as they eventually die.

As well as planning for this scenario, urban tree managers must also allow for a proportion of mortality within the younger age classes in order to produce planting programs that will deliver maximum benefits over time.

Tree Cover and Leaf Area

Tree species that contribute the most leaf surface area in Torbay are:

Ash

Sycamore

Leyland Cypress

List of the ten most important tree species in Torbay.

Species	I.V.
Ash	31.1
Sycamore	26.4
Leyland Cypress	17.5
Hazel	12.4
Beech	9.4
Holm Oak	9.3
Elm	7.7
Lawson Cypress	6.2
Hawthorn	6.2
Oak	6.0

Numerous benefits derived from trees are directly linked to the amount of healthy leaf surface area that they have.

The importance value (IV) is calculated taking into account the leaf area and relative abundance of the species. In Torbay the most important species in the urban forest are ash, sycamore and Leyland cypress, because they contribute the largest leaf areas.

Plate 5: The Ash, identified as the most important tree species in Torbay due to its size, population and leaf area.

Tree species such as Leyland cypress and hawthorn have a much smaller percent of leaf area compared to their percent of population as they are either smaller in stature (hawthorn) or in the case of Leyland cypress kept small (as hedges) through pruning.

A high importance value does not necessarily mean that these trees should be used in the future. Rather, it shows which species are currently delivering the most benefits based on their population and leaf area. These species currently dominate the urban forest structure and are therefore the most important in delivering benefits.

Particularly impressive are Torbay's oaks, which although not in the top ten by total population number (ranked 13th), are in the top ten most important trees due to their larger than average size (and therefore larger leaf area).

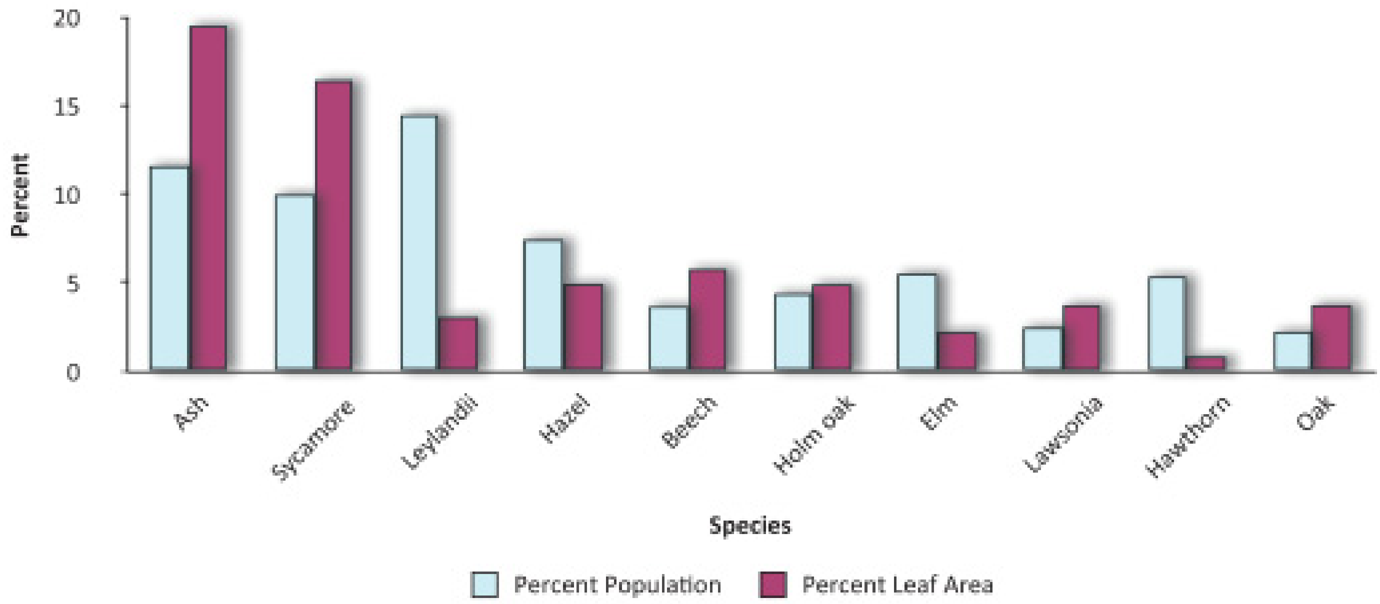


Fig 6: Ten most important tree species in Torbay

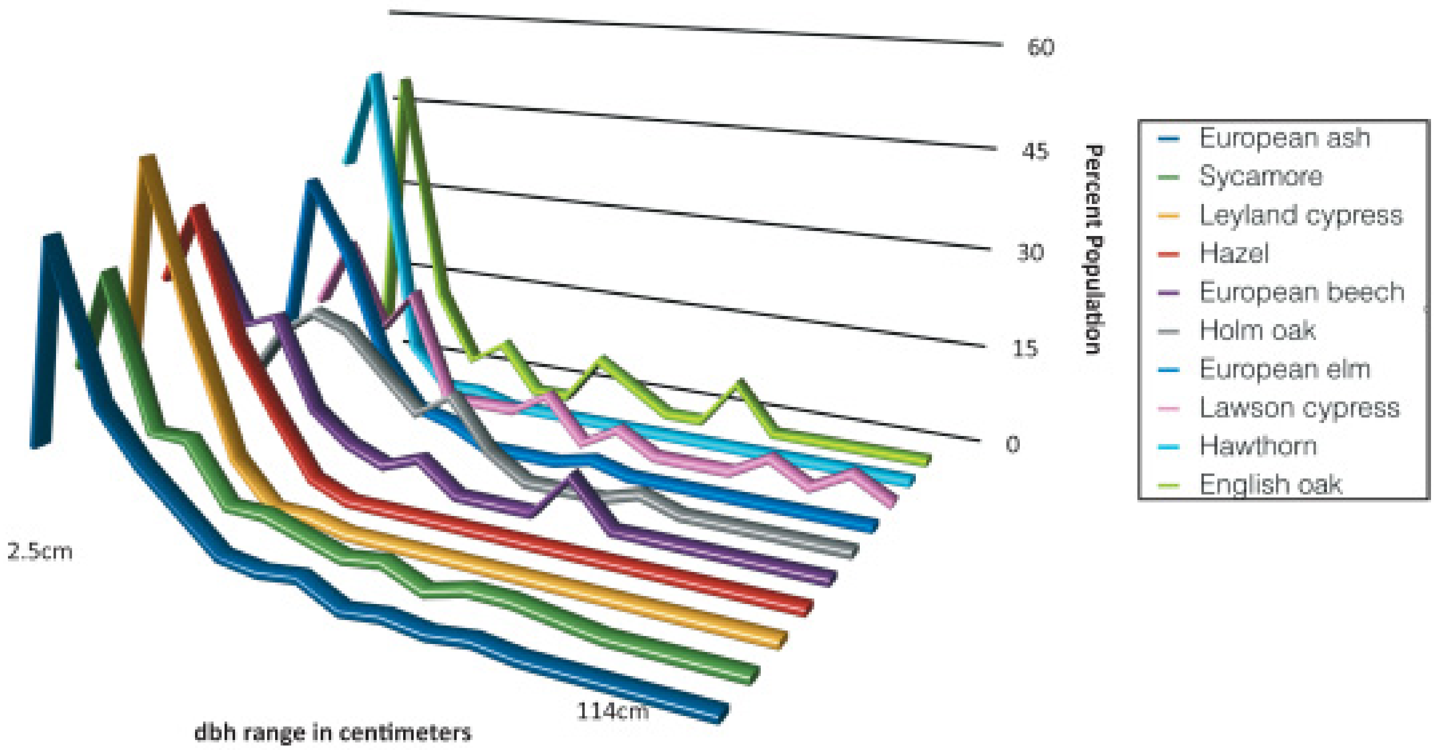


Fig 7: Ten most important tree species and dbh distribution

See Appendix III for the full list of tree importance ranking in Torbay.

Kenton Rogers

Oak at Cockington Manor, one of the largest trees sampled. In a Natural England study using the i-Tree data (Sunderland et al. in press), this oak was shown to return a cost benefit of 1:4.7 based on all the costs but just 2 of its benefits (carbon sequestration and air pollution filtration). Conversely the cherry (pictured below) returned a ratio of 1:0.01

Larger trees have a greater functional value and provide increased benefits to the residents of Torbay (details of functional value and the resulting benefits are discussed later). It has been estimated in previous studies[5] that a 75cm diameter tree can intercept 10 times more air pollution, can store up to 90 times more carbon and contributes up to 100 times more leaf area to the tree canopy than a 15cm tree.

Plate 6: Larger Trees such as this oak in Torre Abbey Meadow live longer and attain a larger size, providing maximum benefits. In this particular case the carefully considered and proactive management of the tree - chestnut fencing and mulching - will ensure it continues to do so for some time.

Fig 8 (below) illustrates how the larger trees contribute more leaf area despite having lower population (compare with Fig 5).

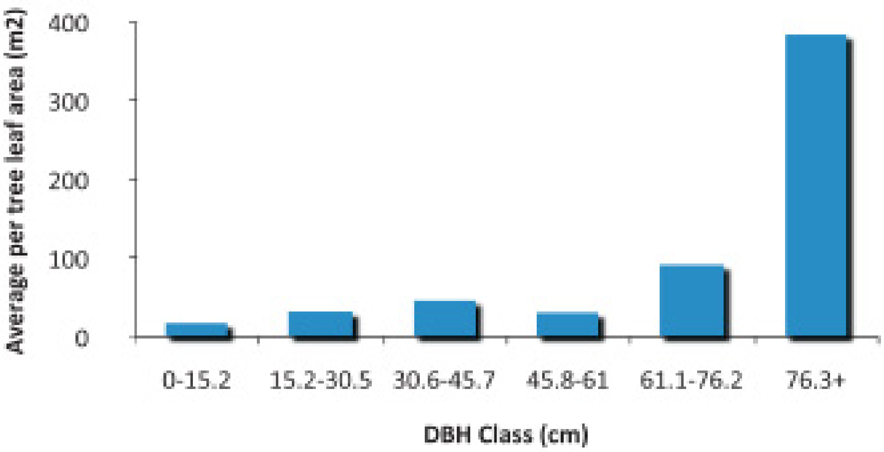


Fig 8: Tree leaf area by dbh

[5] Every Tree Counts - A portrait of Toronto's Urban Forest

Air Pollution Removal and Urban Trees

Tim Jarratt

Torbay's urban forest removes particulate matter (PM10's) equivalent to the annual emissions from 53,000 large family cars.

In the United Kingdom the government estimate that at least 24,000 people die each year as a result of air pollution. (NUFU, 1999).

Poor air quality is a common problem in many urban areas. Air pollution caused by human activity has become a problem since the beginning of the industrial revolution. With the increase in population and industrialization, and the use of transport based on fossil fuels, large quantities of pollutants have been produced.

The problems caused by poor air quality in urban areas are well known, ranging from human health impacts to damage to buildings.

Trees make a significant contribution to improving air quality by reducing air temperature (lowering ozone levels), by directly removing pollutants from the air, absorbing them through the leaf surfaces and by intercepting particulate matter (eg: smoke, pollen, ash and dusts). They also indirectly reduce energy consumption in buildings, leading to lower air pollutant emissions from power plants.

Pollutant	Tons removed per year	Value
Carbon monoxide (CO)	0.0005	£ 0.47 (USEC)
Nitrogen dioxide (NO_2)	7.9	£ 51,673 (USEC)
Ozone (O_3)	22.9	£ 149,416 (USEC)
Particulates PM10's	18	£ 1,315,767 (UKSDC)
Sulphur dioxide (SO_2)	1.3	£ 2,123 (UKSDC)

Table 4: Value of the pollutants removed and quantity per-annum. Valuation method's used are US externality cost (USEC) and UK social damage cost (UKSDC) where they are available.

As well as reducing ozone levels, it is well known that a number of tree species also produce the volatile organic compounds (VOCs) that lead to ozone production in the atmosphere. The i-Tree software accounts for both reduction and production of VOCs within its algorithms, and the overall effect of Torbay's trees is to reduce ozone through evaporative cooling.[6]

Total pollution removal per ha in Torbay is 0.002 t ha^{-1} yr^{-1}. These values were lower than have been recorded by other studies 0.009 t ha^{-1} yr^{-1} for a site in London[7] (PM_{10} only) and .023 t ha^{-1} yr^{-1} for a site in Guangzhou, China[8]. However, the greater pollution concentrations and canopy cover areas observed in these studies will result in more pollutants being removed.

6 Nowak et al, 2000.

7 Tiwary et al (2009)

8 Jim and Chen (2008)

Greater tree cover, pollution concentrations and leaf area are the main factors influencing pollution filtration and therefore increasing areas of tree planting have been shown to make further improvements to air quality[9]. Furthermore, because filtering capacity is closely linked to leaf area it is generally the trees with larger canopy potential that provide the most benefits.

"Due to the larger surface area of needles, coniferous trees have a larger filtering capacity than trees with deciduous leaves. Also the needles are not shed during the winter, when the air quality is at its worst. Nonetheless, coniferous trees are more sensitive to air pollution compared to deciduous trees. Deciduous tree are better at absorbing gases too; it therefore seems that a mix of both species are suitable in the urban landscape.

(Bolund and Hunhammer, 1999).

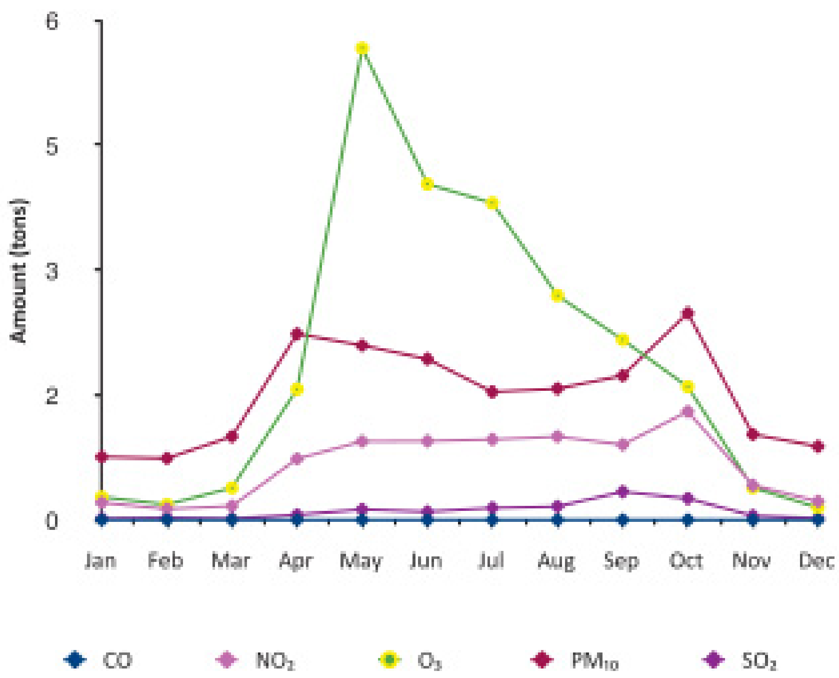


Fig: 9 Monthly Pollution Removal

Pollution removal by trees in Torbay is highest in the summer months (see fig 9), as there is greater leaf surface area during this period and greater stomatal activity due to the increased day light hours. It's also worth noting that generally, pollution levels are higher during this period of the year too.

Pollution removal was greatest for ozone. It is estimated that trees and shrubs remove 50 metric tons of air pollution ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 10 microns (PM10), and sulfur dioxide (SO_2) per year with an associated value of over £1.5 million (based on estimated median externality costs associated with pollutants and UK social damage costs published by DEFRA)[10].

9 Escobedo and Nowak (2009)

10 DECC (2011)

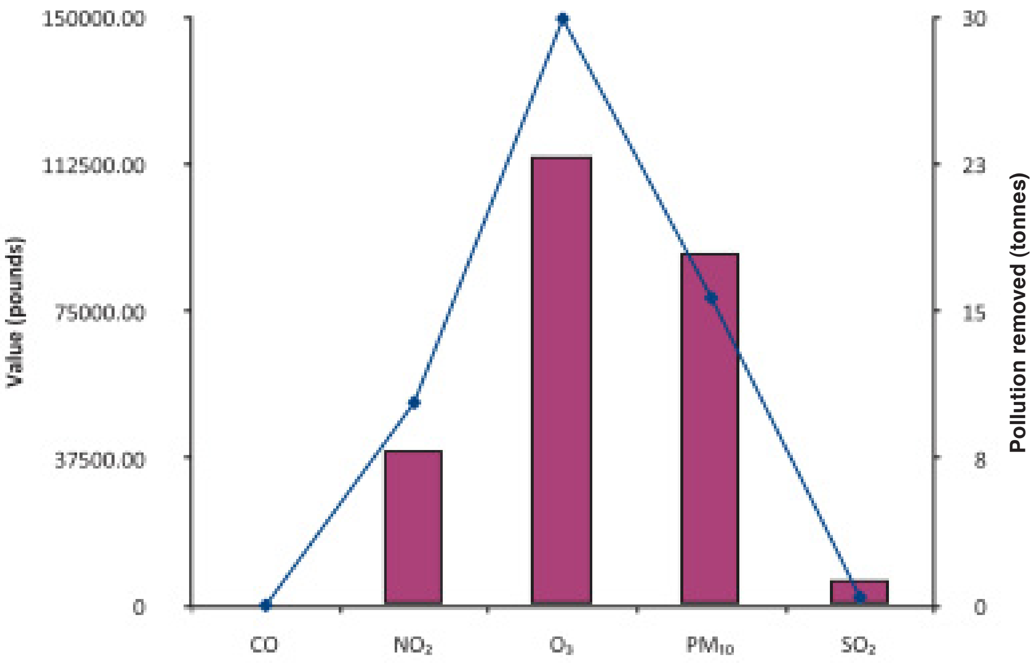
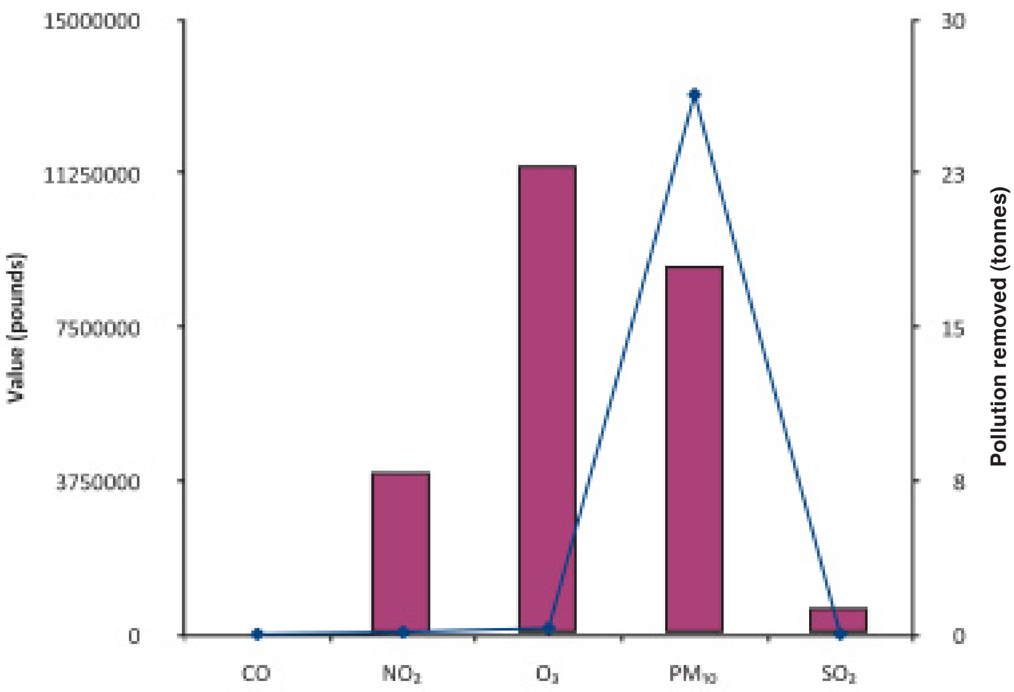
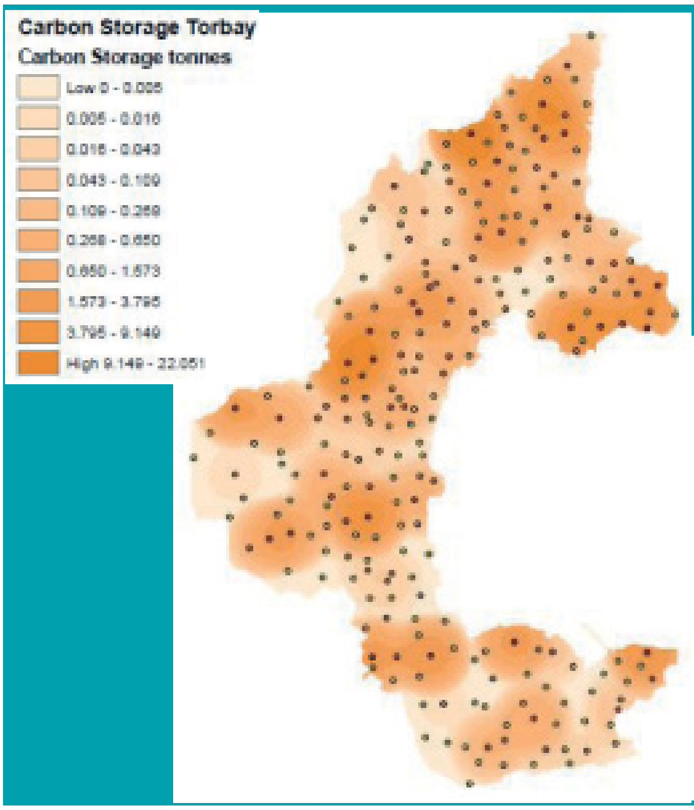
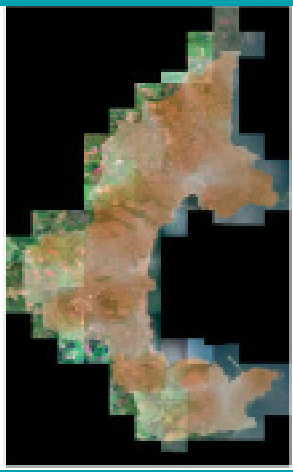


Fig 10: Pollutants removed (bars) and value (lines). (USEC) Top graph and (UKSDC) bottom graph.







Maps of the carbon stored in Torbay's urban forest. The map was created using the i-Tree Eco data as a decision support to focus new planting in areas where it could have the greatest impact. Sample plots are indicated by the small dots, the darker the dot the greater the tree density and therefore, carbon stored.

Carbon Storage and Sequestration

Urban trees can help mitigate climate change by sequestering atmospheric carbon as part of the carbon cycle. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots act store up carbon for decades or even centuries[11]. Over the lifetime of a tree, several tons of atmospheric carbon dioxide can be absorbed[12].

For the 2005/06 period Torbay's baseline CO_2 emissions were estimated at 750,000 tonnes. The sectoral split (fig 11) shows that the majority of these emissions were derived almost equally from the energy used within the domestic and commercial/industrial sectors[13].

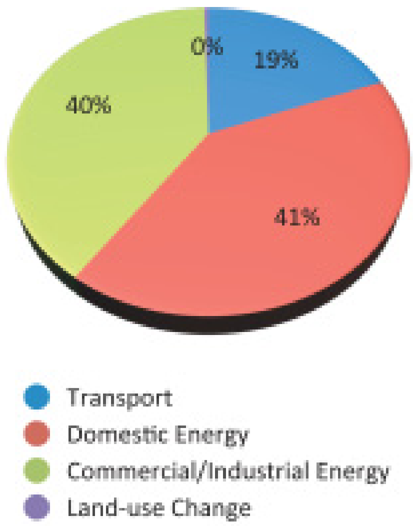


Fig 11: Torbay's Carbon emissions sources

11 Kuhns, 2008

12 McPherson, 2007

13 Torbay 2008

Carbon storage:

Carbon currently held in trees tissue (roots, stem, and branches).

Carbon sequestration:

Estimated amount of carbon removed annually by trees: Net carbon sequestration can be negative if emission of carbon from decomposition is greater than amount sequestered by healthy trees.

"Woodlands of the United Kingdom are estimated to absorb about 2 percent of the annual greenhouse gas emissions"

(Kinver, 2011).

An estimated 98,100 tonnes (approximately 15.4 tonnes/ha) of carbon is stored in Torbay's trees with an estimated value of 5.1 million pounds (based on DEFRA's current carbon figures)[14].

Carbon storage by trees is another way that trees can influence global climate change. As trees grow they store more carbon by holding it in their tissue. As trees die and decompose they release this carbon back into the atmosphere. Therefore the carbon storage of the urban forest is an indication of the amount of carbon that could be released if all the trees died.

Maintaining a healthy tree population will ensure that more carbon is stored than released. Utilizing the wood in long term wood products or to help heat buildings or produce energy will also help to reduce carbon emissions from other sources, such as power plants.

The gross sequestration of Torbay's trees is about 4,280 tonnes of carbon per year (approximately 671 kg/yr/ha). Net carbon sequestration in the urban forest is about 3,320 tonnes, which takes into account the carbon released by dead and dying trees. The value of the carbon sequestrated is estimated at £172,000 per year.

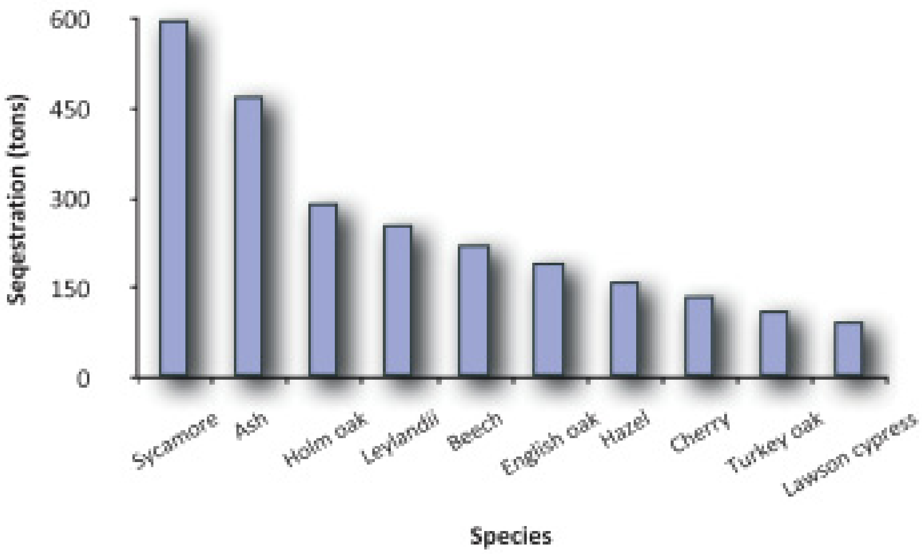


Fig 12: Ten most significant tree species for carbon sequestration currently in Torbay.

Sycamore, ash and Holm oak are currently the most important trees in Torbay in terms of carbon sequestration. Sycamore trees hold approximately 18.5% of the total carbon stored. By contrast, elm, which is the 7th most populous tree, is actually a net contributor of carbon emissions due to the fact that it succumbs to Dutch Elm Disease from an early age.

[14] DECC (2009)

Dave Hansford

Large trees are particularly important carbon stores and new plantings such as these, which have also been adequately protected from mower damage will help to ensure that current levels are maintained.

Based on the figures from the study, Torbay's urban forest can offset the annual emissions from 592 residents. However, Torbay's annual emissions represent over 7 times more than the total current carbon storage of the urban forest, equating to 5.6tC per capita. This means that the urban forest sequestration absorbs less than 0.5% of the total emissions.

The direct impacts of Torbay's trees on carbon seems at first glance to be negligible. However, the potential for the urban forest to reduce CO_2 emissions through energy reduction, and its role in climate adaptation, lowering urban temperatures through evaporative cooling and protecting soil carbon should not be overlooked. Although these particular ecosystem functions were not quantified as part of this study, increasing green cover by 10% within urban areas in Manchester could reduce surface temperatures by 2.2 °C - 2.5 °C [15].

Torbay has a large proportion of smaller (both in age and ultimate size potential) trees and carbon sequestration from small trees is minimal. However a proportion of these trees will grow thus offsetting the decomposition from tree mortality.

Trees also play an important role in protecting soils, which is one of the largest terrestrial sinks of carbon. Soils are an extremely important reservoir in the carbon cycle because they contain more carbon than the atmosphere and plants combined.

The estimates of carbon stored in Torbay's urban forest are likely to be conservative as soil carbon has not been factored into the evaluation. The urban forest can also reduce emissions indirectly, and by planting more trees able to achieve a larger size, additional carbon can be stored in the urban forest. However, tree establishment and maintenance operations will offset some of these gains.

15 Gill et al (2007)

The urban forest has a structural value which is based on the depreciated replacement cost of the actual tree.

Urban forests also have a functional value - based on the functions which the tree performs.

Large, healthy long lived trees provide the greatest structural and functional value.

Structural Values

Urban forests have a structural value based on the trees themselves (the theoretical cost of having to replace a tree with an identical tree). They also have functional values (either positive or negative) based on the functions the trees perform.

By implementing care and positive management the structural value of an urban forest can increase as there is a rise in the number and size of healthy trees. Annual functional values also tend to increase with increased number and size of healthy trees.

However, the values and benefits can also decrease as the amount of healthy tree cover declines. Based on actual urban forestry data collected for Torbay, the i-Tree model estimates the structural and functional value of Torbay's urban forest as follows:

Total structural values of Torbay's urban forest:

Structural (replacement) value:	£ 280 million
Carbon storage:	£ 5,101,200

Annual functional values of Torbay's urban forest:

Carbon sequestration:	£ 172,640
Pollution removal:	£ 1,518,979

The most significant trees in terms of structural value in Torbay are Sycamore, Ash and Holm oak. This is due to the abundance of the species, and their current (and potential) maximum size.

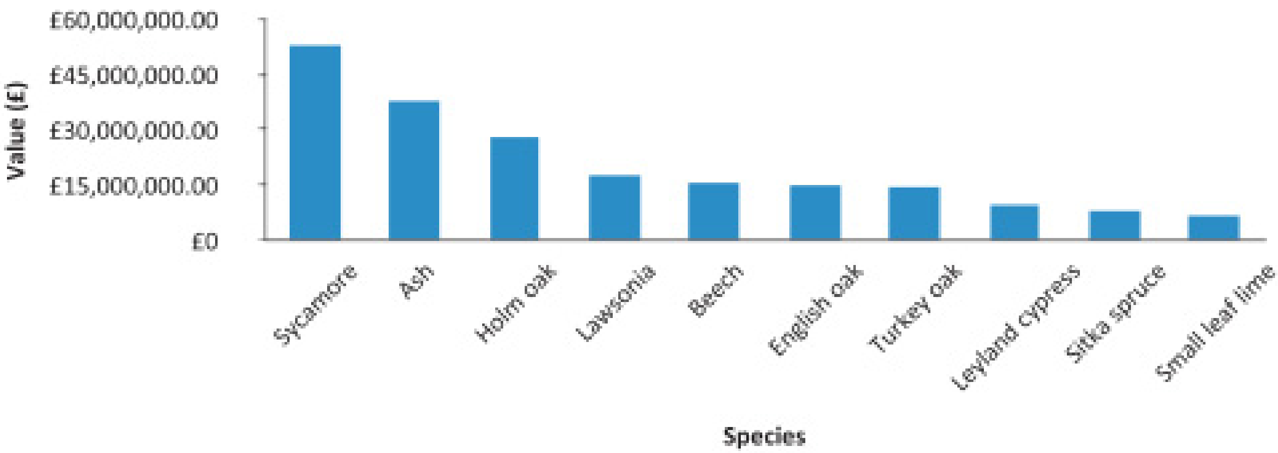


Fig 13: Structural value of the 10 most valuable tree species in Torbay.

Tree diversity

Challenges exist in valuing biodiversity because it is difficult to identify and measure the passive non-use values of biodiversity[16]. However, biodiversity is important because it provides a wide range of indirect benefits to humans.

Although i-Tree Eco does not yet calculate a valuation of biodiversity it does provide an indication of tree species diversity using diversity indexes (Shannon, Simpson and Menhinick). This is important because the diversity of species within the urban forest (both native and exotic) will influence how resilient the tree population will be to future changes, such as minimizing the overall impact of exotic pests, diseases and climate change.

Plate 7: New tree planting of the North American Tulip Tree, which will grow up to 20-35m tall. Although not native these trees cope very well in our urban environment and provide good shade.

16 Nunes et al, 2001

There are more palms in Torbay than there are native oaks and also more Holm oaks than the native oak too.

Although larger oaks provide more in the way of benefits all these species contribute to the diversity of the urban forest.

Torbay's palms are also important in their contribution to the character of Torbay, defining an area well known as 'The English Riviera'.

Many native species are not able to thrive in the artificial environments of our urban areas, and the effects of climate change will exacerbate the situation[17]. For example; the range of Beech is predicted to contract from its current range to more northern reaches of Britain and many other broadleaf and conifer species will also be affected[18], whereas non-native species, such as Holm oak, could become increasingly important for the delivery of benefits in Torbay.

Species selection is an important consideration because there is also potential for some exotics to out-compete and displace native species and reduce native species habitat. Trees from every continent are represented within the tree population of Torbay which is made up of 35 % native species, 40% of European origin and 25% of exotic species from the rest of the world.

102 species were sampled in Torbay equating to approximately 10 species p/ha with a calculated Shannon diversity index of 3.32 (On this scale 1.5 is low and 3.5 is high). This result represents a fairly diverse tree-scape, which one might hope will be more resilient than that represented by one which is more homogenous.

The Barcelona study[19] reported a Shannon index of 3.27 and so Torbay's tree diversity compares favourably with this mediterranean city.

Species	Species/ha	SHANNON	MENHINICK	SIMPSON	EVENNESS
102.00	10.46	3.32	2.96	15.31	0.72

Table 5: Species Richness and Diversity Indexes for Torbay

Spp: is the number of species sampled.

SPP/ha: is the number of species found per hectare of area sampled.

SHANNON: is the Shannon – Wiener diversity index, which assumes that all species within the area have been sampled. It is an indicator of species richness and has a moderate sensitivity to sample size.

MENHINICK: is the Manhinick's index. It is an indicator of species richness and has a low sensitivity to sample size and therefore may be more appropriate for comparison between cities.

SIMPSON: is Simpon's diversity index. It is an indicator of species dominance and has a low sensitivity to sample size and therefore may be more appropriate for comparisons between land-use types.

EVENNESS: is the Shannon – Wiener diversity index, which assumes that all species within the area have been sampled. It is an indicator of species evenness and has a moderate sensitivity to sample size and therefore land-use and/or cities may not be comparable

17 Gill et al 2007

18 Broadmeadow et al 2005

19 Chapparro and Terradas 2009

Potential Pest and Disease Impacts

© Forest Research

Asian longhorn beetle

© David Cappaert, Michigan State University

The Emerald ash borer

Various insects and diseases can infect trees, potentially killing them and reducing the health, value and sustainability of the urban forest. As various pests have different tree hosts, the potential damage or risk of each pest will differ. Four pests were analysed for their potential impact: Asian longhorned beetle, Acute oak decline, Emerald ash borer and *Phytophthora ramorum*.

Fig 14 (below) illustrates the percentage species susceptibility to these identified threats.

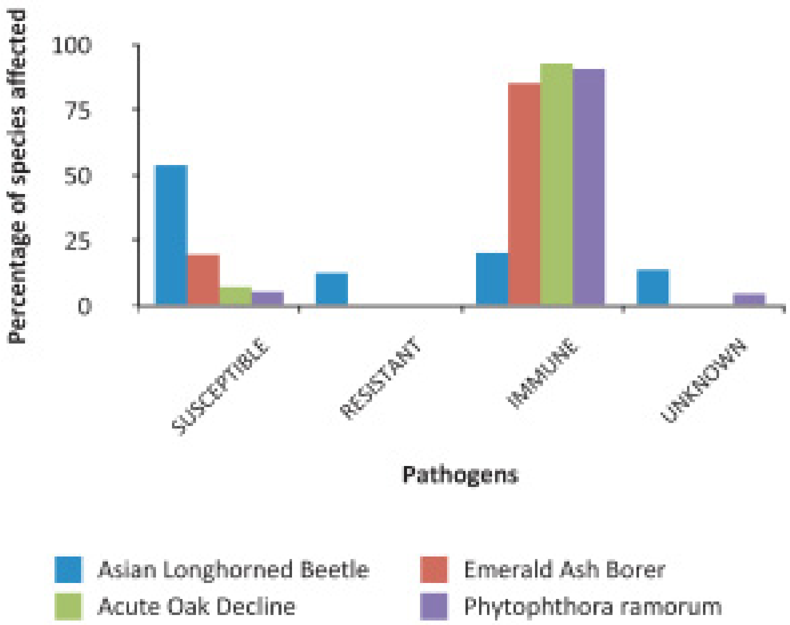


Figure 14: Potential number of trees that could be affected by pathogens.

The Asian longhorned beetle (ALB) is an insect that bores into and kills a wide range of hardwood species. This beetle represents a potential loss to Torbay's urban forest of £121,012,561 in structural value (53.7 percent of live tree population). It represents the most significant threat but has not yet been found in the UK.

However, specimens of ALB have been intercepted at many locations across North America dealing with imported materials, which has caused several alerts across Britain by the Forestry Commission. There is no evidence to suggest that it has successfully attacked any tree in the UK yet.

The main risk of ALB getting into Britain is at its larval stage, when it is protected within untreated wood imported into the UK. This is how the infestation and subsequent tree damage came about in the USA. There is also potential for the beetle to be transported into Britain by packaging material from China. If the beetle were to become established in Britain there is likely to be extensive damage to both urban and woodland/forest trees.

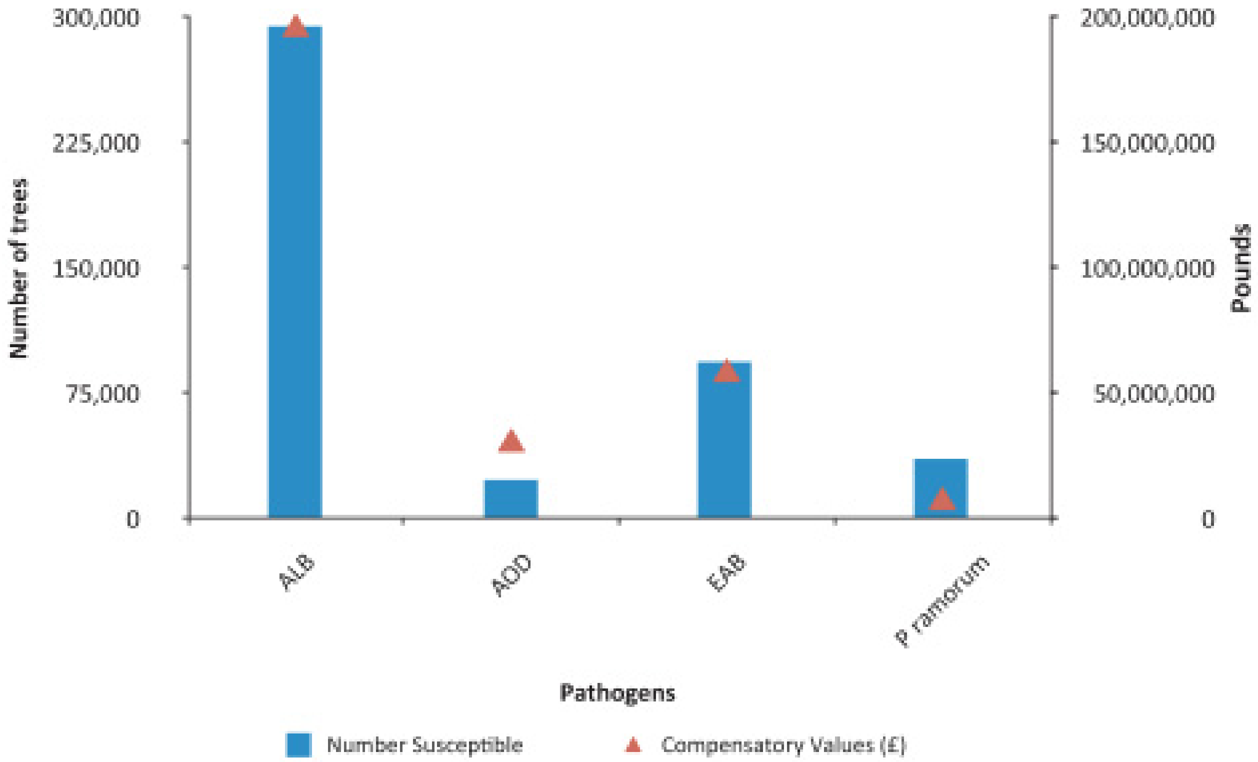


Figure 15: Potential number of trees affected by pathogens and associated value.

Acute Oak Decline (AOD) is a disease that affects native Oaks and is a serious concern. It mainly affects mature oak trees. Unlike chronic oak decline, acute oak decline can lead to the death of trees within 4 to 5 years of symptoms appearing, potentially causing a £295,327.82 loss to Torbay‘s urban forest.

Emerald ash borer (EAB) is an exotic beetle that originates from North America and causes significant damage to ash trees. Symptoms start of as initial thinning or yellowing of the foliage. Death of infected trees can be within 2-3 years after first showing signs of ill health. EAB has the potential to affect 19.5 percent of Torbay‘s live tree population or £ 356,602.33 in structural value.

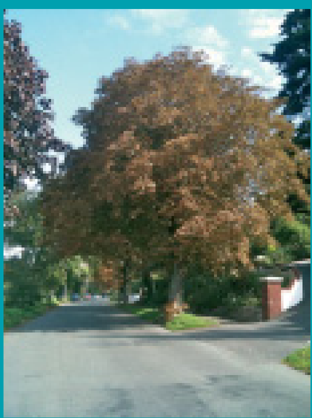
There is no evidence to date that the emerald ash borer is present in the UK, but the increase in global movement of imported wood and wood packaging poses a significant risk of its accidental introduction.


Kenton Rogers

Healthy, well maintained trees (like the Lime above) that have adequate, un-compacted rooting space are better able to deal with pests and diseases.

Trees that are stressed are more susceptible to succumb and less likely to recover from these issues.

It is therefore important to ensure that trees are properly planted and maintained.


Kenton Rogers

Phytophthora ramorum is a fungus-like pathogen of plants that is causing extensive damage and mortality to trees and other plants in parts of the United Kingdom. Such a pathogen could cause a £639,452.25 loss to Torbay's urban forest.

By far the most important factor when dealing with any potential pest or disease impact is to consider the health of the tree. Tree condition was measured as part of the survey and fig 16 below shows the overall health of the trees in Torbay.

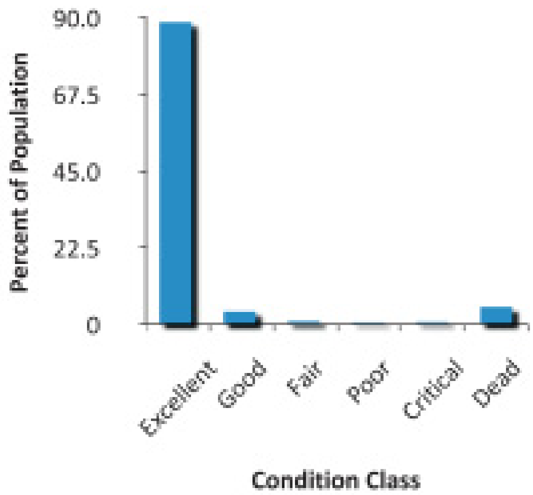


Fig: 16 Overall tree condition

Nearly ninety percent of the trees in Torbay are in excellent condition (exhibiting less than 5% dieback). The small amount of dead trees is also acceptable as they are very important for biodiversity. Fig 17 shows the health of the 10 most common trees in Torbay and plainly illustrates the effect of Dutch Elm Disease on that particular species.

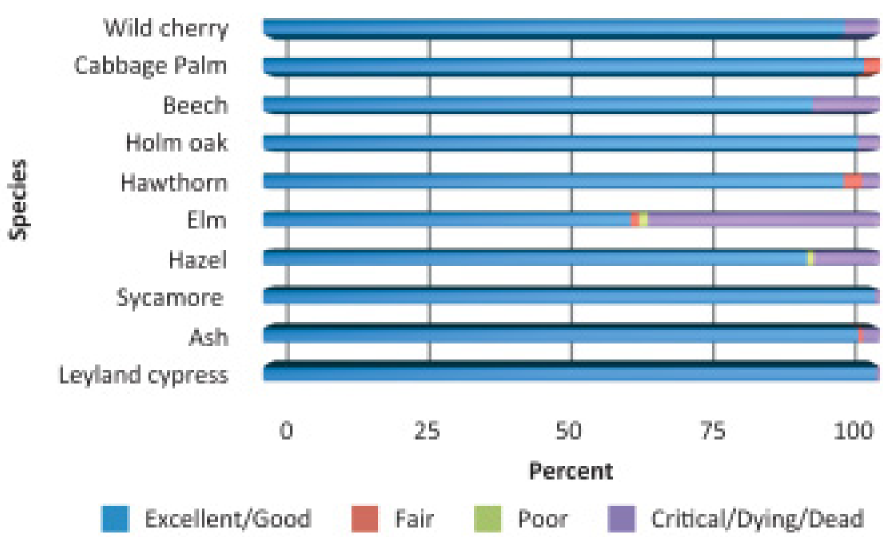


Fig 17: Condition of the 10 most common trees in Torbay

"The urban forest is an important part of the urban ecosystem, being a set of interacting species, and their local non-biological environment, which, functioning together, sustain life." Bolund and Hunhammar (1999)

Livermead Head, Torquay

Neil Coish

Conclusions

Torbay's trees provide a valuable public benefit. This public benefit is delivered by trees situated on both public and private property.

Any reduction in privately owned trees will reduce this benefit. Strategies and policies that will serve to conserve this important resource, through education and community engagement or through planning policy or TPO use should be considered to address potential loss.

Torbay's urban forest provides the equivalent of at least £1.5 million in ecological services each year. The benefits derived from these trees significantly exceed the annual cost in management.

Torbay has more trees per hectare than many US and European cities. However, Torbay's trees are smaller in size thereby supporting less canopy cover than other comparable cities. Nevertheless, canopy cover in Torbay is higher than the UK national average.

Canopy cover can be increased through new tree plantings but the most effective strategy for increasing average tree size and tree canopy is to preserve and manage the existing trees in the borough so that a good proportion grow to maturity.

Torbay has a good diversity of tree species but a greater proportion of larger trees will increase these benefits because the size of a tree and the amount of healthy leaf area equates directly to the provision of benefits (or ecosystem services).

The values presented in this study represent only a portion of the total value of the urban forest of Torbay because only a proportion of the total benefits have been evaluated. Trees confer many other benefits. Therefore, the values presented in this report should be seen as conservative estimates.

Climate change could affect the tree stock in Torbay in a variety of ways and there are great uncertainties about how this may manifest. Further research into this area would be useful in informing any long term tree and woodland strategies.

The challenge now is to ensure that policy makers and practitioners take full account of urban trees and woodlands in decision making. Not only are trees a valuable functional component of our urban fabric they also make a significant contribution to peoples quality of life.

[20] de Groot et al (2010)

Bibliography

Baldocchi, D (1988). A multi layer model for estimating sulfur dioxide deposition to a deciduous oak forest canopy. Atmospheric Environment 22, 869-884.

Baldocchi, D., Hicks, B., Camara, P (1987). A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. Atmospheric Environment. 21, 91-100.

Bidwell, R., Fraser, D (1972). Carbon monoxide uptake and metabolism by leaves. Canadian Journal of Botany 50, 1435-1439.

Bolund, P., Hunhammar, S (1999). Ecosystem services in urban areas. Ecological Economics 29, 293-301.

Britt, C., Johnston, M (2008). Trees in Towns II - A new survey of urban trees in England and their condition and management. Department for Communities and Local Government, London.

Broadmeadow, M., Ray, D., Samuel, C (2005). Climate Change and the future for broadleaved tree species in Britain. Forestry 78, 145.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P., van den Belt, M., (1997). The Value of the worlds ecosystem services and natural capital. Nature 15, 253-260.

Chapparro and Terradas (2009). Ecological Services Of Urban Forest in Barcelona [Online] Available at: http://itreetools.org/resources/reports/Barcelona%20Ecosystem%20Analysis.pdf [Accessed 15 Nov 2011].

DECC (2009). Carbon appraisal in UK policy appraisal [Online] Available at: http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/carbon%20valuation/1_20090715105804_e_@@_carbonvaluationinukpolicyappraisal.pdf [Accessed: Nov 3 2011].

DEFRA (2007). The air quality strategy for England, Scotland, Wales and Northern Ireland. DEFRA. London.

De Groot, R., Alkemade, R., Braat, L., Hein, L., Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7, 260-270.

Escobedo, F., Nowak, D (2009). Spatial heterogeneity and air pollution removal by an urban forest. Landscape and Urban Planning, 2009 Vol. 90 (3-4) pp. 102-110.

Every Tree Counts (2010). A Portrait of Toronto's Urban Forest [Online] Available at: http://www.toronto.ca/trees/pdfs/Every_Tree_Counts.pdf [Accessed Sep 10 2011].

Gerhald, H., Frank, S (2002). Our heritage of community trees. Pennsylvania Urban and Community Forestry Council.

Gill, S., Handley, A., Ennos, A., Paulett, S (2007). Adapting cities for climate change: the role of green infrastructure. Built Environment 33 (1), 115-133.

Hothersall, T. (2006). Trees, woodlands and green infrastructure in urban regeneration. Woodland Trust. New woods, new lives, and new landscape. Manchester.

Hollis, A. (2007) Depreciated replacement cost in amenity tree valuation. UKI-RPAC guidance note 1.

IGCB. Air quality damage costs per tonne, 2010 prices [Online]. Available at:http://

www.defra.gov.uk/environment/quality/air/air-quality/economic/damage/ [Accessed: May 20th 2011].

i-Tree. (2010) 'i-Tree software suite v3.1' [Online] Available at: http://www.itreetools.org/resources/manuals.php [Accessed: Jan 12 2011].

Jim, C.Y., Chen, W., (2008) Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). Journal of Environmental Management 88, 665-676.

Kniver, M. (2011) Urban plants' role as carbon sinks 'underestimated' BBC. [Online] Available at: http://www.bbc.co.uk/news/science-environment-14121360 [Accessed: July 28 2011].

Kuhns, M (2008). Landscape trees and global warming. [Online] Available at: http://www.doughnut/articles/landscape%20trees%20and%20global%20warming%20-%2... 1/15/2008 [Accessed: Sep 2 2011].

Lawton Report (2010). Making space for nature [Online] Available at: http://archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf [Accessed: Nov 12 2011].

Lovett, G (1994). Atmospheric deposition of nutrients and pollutants in North America: an ecological perspective. Ecological Applications 4, 629-650.

McPherson, G. (2000). Expenditures associated with conflicts between street tree roots growth and hardscape in California. Journal of Arboriculture 6, 289-297.

McPherson, B., Sundquist, E (2009). Carbon sequestration and its role in the global carbon cycle. American Geophysical Union 183.

The Natural Choice (2011). Securing the value of nature [Online] Available at: http://www.archive.defra.gov.uk/environment/natural/documents/newp-white-paper-110607.pdf [Accessed: Nov 12 2011].

Nowak, D. (1994) Atmospheric carbon dioxide reduction by Chicago's urban forest. In, McPherson, E., Nowak, D., Rowntree, R., (Eds). Chicago's urban forest ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service, Radnor, PA.

Nowak, D., Civerolo, K., Rao, S., Sistla, G,. Luley, C., Crane, D. (2000). A modeling study of the impact of urban trees on ozone. Atmospheric Environment 34, 1601-1613.

Nowak, D., Hoehn, R., Crane, D., Stevens, J., Leblanc F. (2010). Assessing urban forest effects and values, Chicago's urban forest. Resource bulletin NRS-37. USDA Forest Service, Radnor, PA.

Nowak, D., Crane, D., (2002) Carbon storage and sequestration by urban trees in the USA. Environmental Pollution 116, 381-389.

Nunes, P., and van de Bergh, J (2001). Economic valuation of biodiversity: sense or nonsense? Ecological Economics 39, 203-222

Rogers, K,. Hansford, D., Sunderland, T., Brunt, A., Coish, N., (2011) Measuring the ecosystem services of Torbay's trees: The Torbay i-Tree Eco pilot project. Proceedings of the ICF - Urban Tree Research Conference. Birmingham, April 13-14, Article in press.

Stewart, S., Owen, S., Donovan, R., MacKensie, R., Hewitt, N., Skilba, U., Fowlar, D (2003). Trees and sustainable urban air quality: using trees to improve air quality in cities. Lancaster University, Lancaster.

Sunderland, T., Rogers, K., Coish, N. (2011). 'What proportion of the costs of urban trees can be justified by the carbon sequestration and air quality benefits they provide?' Proceedings of the Arboricultural Association 2011 Conference. Warwick, September 19–20, article in press.

Tiwary, A., Sinnet, D., Peachey, C., Chalabi, Z,. Vardoulakis, S., Fletcher, T., Leonardi, G., Grundy, C., Azapagic, A., T, Hutchings. (2009). An integrated tool to assess the role of new planting in PM_{10} capture and the human health benefits: A case study in London. Environmental Pollution 157, 2645-2653.

Torbay Council (2011). Torbay Statistics [Online] Available at: http://www.torbay.gov.uk/factsfigures [Accessed 20 June 2011].

Torbay Council (2008). 'A climate change strategy for Torbay 2008-2013'. [Online] Available at: http://www.torbay.gov.uk/climatechange [Accessed 20 Sep 2010].

Trees for Cities (2005). Trees Matter! National Urban Forestry Unit, Wolverhampton.

UFORE (2010). Methods [Online] Available at: http://www.ufore.org/methods.html [Last Accessed 22 Feb 2011].

UK National Ecosystem Assessment (2011). [Online] Available at: http://uknea.unep-wcmc.org/ [Accessed 2 June 2011]

Wolf, K. (2007). The environmental psychology of shopping. ICSC Research Review Vol. 14, No 3.

Woodland Trust (2004). Space for people [Online] Available at: http://www.woodlandtrust.org.uk/sitecollectiondocuments/pdf/spaceforpeople.pdf [Accessed 14 July 2011].

Zinke, P (1967). Forest interception studies in the United States. In Sopper, W., Lull, H., eds. Forest hydrology. Oxford, UK: Pergamon Press 137-161.

Appendix I. Comparison of Urban Forests

How does Torbay compare to other cities? Comparison among cities at the global scale should be made with caution as there are many attributes of a city which will effect urban forest structure and function. Summary data are provided here from other cities analysed using the UFORE i-Tree Eco model. All values are (USEC).

I. City totals, trees only

City	% Tree cover	Number of trees	Carbon storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (tons/yr)	Pollution value U.S. $
Calgary, Canada	7.2	11,889,000	445,000	21,400	326	2,357,000
Atlanta, GA	36.7	9,415,000	1,344,000	46,400	1,663	12,213,000
Toronto, Canada	20.5	7,542,000	992,000	40,300	1,212	8,952,000
New York, NY	20.9	5,212,000	1,350,000	42,300	1,677	11,834,000
Chicago, IL	17.2	3,585,000	716,000	25,200	888	6,398,000
Baltimore, MD	21.0	2,627,000	597,000	16,200	430	3,123,000
Philadelphia, PA	15.7	2,113,000	530,000	16,100	576	4,150,000
Washington, DC	28.6	1,928,000	526,000	16,200	418	2,858,000
Barcelona, Spain	25.2	1,419,823	113,437	6,187	305	1,579,873
Boston, AM	22.3	1,183,000	319,000	10,500	284	2,092,000
Woodbridge, NJ	29.5	986,000	160,000	5,560	210	1,525,000
Minneapolis, MN	26.4	979,000	250,000	8,900	306	2,242,000
Syracuse, NY	23.1	876,000	173,000	5,420	109	836,000
Torbay, UK	**11.2**	**818,000**	**98,100**	**4,279**	**50**	**447,741, (£281,495)**
San Francisco, CA	11.9	668,000	194,000	5,100	141	1,018,000
Morgantown, WV	35.5	658,000	93,000	2,890	72	489,000
Moorestown, NJ	28.0	583,000	117,000	3,760	118	841,000
Udine, Italy	10	162,000	19,100	888	80	463,000
Jersey City, NJ	11.5	136,000	21,000	890	41	292,000
Freehold, NJ	34.4	48,000	20,000	545	22	162,000

Source: USDA Forest Service

Appendix II. Relative Tree Effects

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

Carbon storage is equivalent to:
- Amount of carbon emitted in Torbay in 48 days
- Annual carbon (C) emissions from 64,900 family cars
- Annual C emissions from 32,600 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 551 family cars
- Annual nitrogen dioxide emissions from 367 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 2,090 family cars
- Annual sulfur dioxide emissions from 35 single-family houses

Particulate matter less than 10 microns (PM10) removal is equivalent to:
- Annual PM10 emissions from 52,800 family cars
- Annual PM10 emissions from 5,090 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Torbay in 2.1 days
- Annual C emissions from 2,800 family cars
- Annual C emissions from 1,400 single-family houses

Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) divided by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Carbon dioxide emissions from automobile assumed six pounds of carbon per gallon of gasoline if energy costs of refinement and transportation are included (Graham, R.L., Wright, L.L., and Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO2 Emissions. Climatic Change 22:223-238).

Appendix III. Species Importance Ranking List

Rank	Genus	Species	Common Name	% Population	% Leaf Area	IV [a]
1	*Fraxinus*	*excelsior*	Ash	11.5	19.52	31.1
2	*Acer*	*pseudoplatanus*	Sycamore	9.98	16.42	26.41
3	*Cupressocyparis*	*leylandii*	Leyland cypress	14.46	3.06	17.51
4	*Corylus*	*avellana*	Common hazel	7.43	4.93	12.36
5	*Fagus*	*sylvatica*	Beech	3.67	5.77	9.45
6	*Quercus*	*ilex*	Holm oak	4.39	4.91	9.31
7	*Ulmus*	*spp.*	Elm	5.51	2.22	7.73
8	*Chamaecyparis*	*lawsonia*	Lawson's cypress	2.48	3.74	6.22
9	*Crataegus*	*monogyna*	Hawthorn	5.35	0.84	6.19
10	*Quercus*	*robur*	English oak	2.24	3.75	5.98
11	*Prunus*	*avium*	Wild cherry	2.8	1.71	4.51
12	*Cordyline*	*australis*	Cabbage palm	3.12	0.76	3.88
13	*Quercus*	*cerris*	Turkey oak	0.4	2.94	3.34
14	*Ilex*	*aquifolium*	Holly	2.32	0.7	3.02
15	*Acer*	*campestre*	Field maple	1.28	1.55	2.83
16	*Sambucus*	*nigra*	Elder	2.08	0.7	2.77
17	*Tilia*	*platyphyllos*	Large leaf lime	0.16	2.6	2.76
18	*Malus*	*sylvestris*	Crab apple	1.76	0.91	2.67
19	*Picea*	*sitchensis*	Sitka spruce	0.08	2.52	2.6
20	*Laurus*	*nobilis*	Bay Laurel	1.68	0.74	2.41
21	*Pittosporum*	*tenuifolium*	Kohuhu	1.36	0.74	2.1
22	*Tilia*	*cordata*	Small leaf lime	0.16	1.91	2.07
23	*Taxus*	*bacata*	Yew	0.96	1.06	2.02
24	*Tilia*	*x europaea*	Common lime	0.08	1.6	1.68
25	*Acer*	*platanoides*	Norway maple	0.32	0.92	1.24
26	*Pinus*	*nigra spp. nigra*	Austrian pine	0.32	0.92	1.24
27	*Prunus*	*laurocerasus*	Cherry laurel	0.96	0.24	1.2
28	*Juglans*	*regia*	Black walnut	0.08	0.96	1.04
29	*Pinus*	*sylvestris*	Scots pine	0.32	0.68	1
30	*Salix*	*alba*	White willow	0.24	0.73	0.97
31	*Larix*	*decidua*	Larch	0.4	0.51	0.91
32	*Eucalyptus*	*gunnii*	Eucalyptus	0.32	0.54	0.86
33	*Picea*	*abies*	Norway spruce	0.24	0.59	0.83
34	*Sorbus*	*aucuparia*	Mountain ash	0.56	0.25	0.81
35	*Robinia*	*pseudoacacia*	False Acacia	0.16	0.62	0.78
36	*Cedrus*	*deodara*	Deodar cedar	0.16	0.62	0.77
37	*Prunus*	*spinosa*	Blackthorn	0.64	0.1	0.74
38	*Castanea*	*sativa*	Sweet chestnut	0.24	0.42	0.66
39	*Salix*	*caprea*	Goat willow	0.4	0.25	0.65
40	*Prunus*	*cerasifera*	Cherry plum	0.32	0.31	0.63
41	*Cupressus*	*macrocarpa*	Monterey cypress	0.24	0.36	0.6
42	*Prunus*	*padus*	Bird cherry	0.4	0.2	0.6
43	*Populus*	*nigra*	Black poplar	0.16	0.35	0.51
44	*Trachycarpus*	*fortunei*	Windmill palm	0.32	0.12	0.44
45	*Araucaria*	*araucana*	Monkey puzzle	0.16	0.28	0.44
46	*Acer*	*palmatum*	Japanese maple	0.16	0.27	0.43
47	*Cornus*	*Floria*	Flowering dogwood	0.16	0.26	0.42
48	*Thuja*	*plicata*	Western red cedar	0.24	0.18	0.42
49	*Ostrya*	*carpinifolia*	European hornbeam	0.16	0.22	0.38
50	*Rhododendron*	*spp.*	Rhododendron	0.24	0.14	0.38
51	*Aeculus*	*hipcastanum*	Horse chestnut	0.16	0.22	0.38
52	*Betula*	*pendula*	Silver birch	0.08	0.29	0.37

53	*Laburnam*	*spp.*	Laburnam	0.24	0.11	0.35
54	*Quercus*	*rubra*	Northern red oak	0.08	0.26	0.34
55	*Acacia*	*dealbata*	Silver Wattle	0.24	0.09	0.33
56	*Juglans*	*regia*	Walnut	0.16	0.17	0.33
57	*Griselinia*	*littoralis*	Griselinia	0.24	0.09	0.32
58	*Chamaecyparis*	*spp.*	Chamaecyparis	0.24	0.06	0.3
59	*Pyrus*	*communis*	Common pear	0.24	0.05	0.29
60	*Acer*	*spp.*	Maple	0.08	0.21	0.28
61	*Ligustrum*	*ovalifolium*	Common privet	0.24	0.04	0.28
62	*Arbutus*	*unedo*	Strawberry tree	0.24	0.04	0.28
63	*Eucalyptus*	*regnans*	Mountain ash	0.16	0.12	0.28
64	*Cotoneaster*	*frigidus*	Cotoneaster	0.24	0.03	0.27
65	*Nothofagus*	*obliqua*	Roble Beech	0.16	0.12	0.28
66	*Cornus*	*sanguinea*	Dogwood	0.16	0.08	0.24
67	*Elaeagnus*	*pungens*	Thorny elaeagnus	0.16	0.07	0.23
68	*Aesculus*	x *carnea*	Red horsechestnut	0.08	0.14	0.22
69	*Virburnum*	*spp.*	Viburnum	0.16	0.05	0.21
70	*magnolia*	x *soulangiana*	Saucer magnolia	0.16	0.04	0.2
71	*Quercus*	*petraea*	Sessile oak	0.08	0.12	0.2
72	*Alnus*	*glutinosa*	European alder	0.08	0.11	0.19
73	*magnolia*	*grandiflora*	Southern magnolia	0.08	0.11	0.19
74	*Prunus*	*domestica*	Common plum	0.16	0.02	0.18
75	*Mahonia*	*japonica*	Japanese mahonia	0.16	0.02	0.18
76	*Nothofagus*	*spp.*	Southern beech	0.16	0.02	0.18
77	*Prunus*	*cerasifera*	Flowering plum	0.16	0.01	0.17
78	*Syringa*	*vulgaris*	Common lilac	0.16	0.01	0.17
79	*Prunus*	*spp.*	Cherry *spp.*	0.16	0	0.16
80	*Salix*	*spp.*	Willow *spp.*	0.08	0.08	0.16
81	*Juniperus*	*communis*	Juniper	0.08	0.07	0.15
82	*Abies*	*pinsapo*	Spanish fir	0.08	0.07	0.15
83	*Cotinus*	*spp.*	Smoketree	0.08	0.06	0.14
84	*Liquidambar*	*styraciflua*	Sweet gum	0.1	0.05	0.13
85	*Pyrus*	*spp.*	Pear spp	0.08	0.05	0.13
86	*Acacia*	*spp.*	Acacia	0.08	0.05	0.13
87	*Mespilus*	*germanica*	European medlar	0.08	0.04	0.12
88	*Fuchsia*	*spp.*	Fuchsia	0.08	0.04	0.12
89	*Picea*	*omorika*	Serbian spruce	0.08	0.04	0.12
90	*Amelanchier*	*canadensis*	Eastern service berry	0.08	0.03	0.11
91	*Rhodora*	*spp.*	Rhodora	0.08	0.03	0.11
92	*Abies*	*spp.*	Fir spp	0.08	0.02	0.1
93	*Syringa*	*vulgaris*	Lilac	0.08	0.02	0.1
94	*Lauraceae*	*spp.*	Laurel spp	0.08	0.02	0.1
95	*Yucca*	*spp.*	Yucca	0.08	0.02	0.1
96	*Citrus*	*aurantium*	Orange	0.08	0.02	0.1
97	*Prunus*	*dulcis*	Almond	0.08	0.02	0.1
98	*Pinus*	*mugo*	Mountain pine	0.08	0.02	0.1
99	*Buddleja*	*spp.*	Buddleja	0.08	0.01	0.09
100	*Ulex*	*europaeus*	Gorse	0.08	0.01	0.09
101	*Cydonia*	*oblonga*	Quince	0.08	0.01	0.09
	IV [a] = importance value (% population + % leaf area)					

Appendix IV. Number of trees, leaf area and value

Species	Number of trees	Carbon stored (mt)	Gross Seq (mt/yr)	Net Seq (mt/yr)	Leaf Area (km2)	Leaf Biomass (mt)	Value (USEC)
Leyland cypress	118306	2430.77	268.75	255.68	1.581	370.55	£9,589,526.54
Ash	94776	11399.19	506.6	470.61	10.091	1073.56	£37,810,276.42
Sycamore	81703	18142.32	661.7	597.8	8.493	593.94	£52,888,063.64
Hazel	60787	2344.55	186.59	160.9	2.549	177	£5,674,472.25
Elm	45100	3466.27	112.98	-289.69	1.147	78.09	£1,776,569.40
Hawthorn	43793	800.52	87.54	84.47	0.432	54.4	£2,881,995.55
Holm oak	35949	9934.76	425.14	291.65	2.54	233.13	£27,932,132.63
Beech	30067	7385.11	260.32	222.25	2.984	149.34	£15,594,129.70
Cabbage palm	25491	39.52	1.76	1.6	0.393	29.22	£0.00
Wild cherry	22877	1891.56	162.64	136.66	0.886	68.54	£4,470,244.47
Lawson cypress	20262	3945.47	115.78	94.19	1.936	484.02	£17,606,784.81
Holly	18955	428.23	60.03	58.65	0.364	48.62	£1,262,014.12
English oak	18302	6713.92	211.87	192.47	1.937	128.98	£14,869,758.77
Elder	16994	992.19	64.47	59.83	0.36	26.77	£3,026,980.89
Crabapple	14380	547.54	61.4	32.81	0.471	40.64	£1,269,228.84
Bay laurel	13726	1177.42	94.93	90.98	0.381	28.31	£3,486,425.68
Pittosporum	11112	1038.42	83.55	78.71	0.383	28.42	£2,685,607.30
Field maple	10458	975.14	66.83	63.5	0.802	45.15	£2,540,693.82
Cherry laurel	7844	142.27	26.17	25.63	0.126	9.72	£424,327.08
English yew	7844	320.42	20.95	19.67	0.548	60.48	£1,880,410.24
Blackthorn	5229	57.76	8.08	7.33	0.05	3.87	£176,560.29
Mountain ash	4575	97.47	14.71	14.29	0.13	10.29	£319,587.03
Larch	3268	260.22	11.86	10.41	0.263	14.2	£664,211.99
Bird cherry	3268	92.96	11.12	9.66	0.102	7.9	£167,362.58
Turkey oak	3268	7268.93	132.91	112.23	1.521	139.57	£14,377,583.37
Goat willow	3268	78.75	13.48	13.14	0.127	7.82	£253,320.88
Norway maple	2615	717.84	26.91	25.13	0.478	25.79	£1,776,993.29
Eucalyptus	2615	686.89	33.61	30.93	0.281	36.34	£1,504,031.67
Austrian pine	2615	835.07	23.5	20.31	0.474	45.68	£5,416,495.15
Scots pine	2615	692.59	17.6	17.11	0.353	34.07	£2,990,443.83
Cherry plum	2615	461.85	30.73	26.76	0.16	9.74	£665,591.78
Trachycarpus fortunei	2615	4.68	0.06	0.04	0.062	10.32	£0.00
Silver wattle	1961	46.99	5.95	5.8	0.048	11.49	£120,931.64
Strawberry tree	1961	175.86	11.32	7.22	0.021	1.58	£321,281.27
Sweet chestnut	1961	1369.06	33.66	30.58	0.215	15.05	£4,136,183.17
Chamaecyparis cedar	1961	13.25	2.48	2.42	0.032	8.04	£63,988.47
Cotoneaster	1961	17.48	4.48	4.39	0.014	1.04	£63,988.47
Monterey cypress	1961	70	5.98	5.7	0.188	44.18	£199,730.60
Griselinia	1961	111.7	13.05	12.58	0.044	3.27	£224,912.91
Laburnum	1961	49.38	8.68	8.04	0.059	4.42	£63,384.61

Species	Number of trees	Carbon (mt)	Gross Seq (mt/ yr)	Net Seq (mt/yr)	Leaf Area (km2)	Leaf Biomas s (mt)	Value
Common privet	1961	16.22	3.89	3.81	0.021	1.91	£80,048.88
Roble Beech	1961	196.91	6.38	-29	0.013	0.99	£176,036.86
Norway spruce	1961	223.38	10.99	10.12	0.303	50.55	£770,875.70
Common pear	1961	12.34	3.68	3.61	0.025	1.88	£95,335.99
Rhododendron	1961	39.69	6.58	6.43	0.072	14.44	£85,836.34
White willow	1961	495.73	23.53	22.06	0.378	23.35	£1,575,521.63
Western red cedar	1961	27.66	1.43	1.32	0.092	17.61	£1,040,422.46
Japanese maple	1307	200.71	6.96	6.79	0.14	7.88	£194,716.42
Horse chestnut	1307	121.19	10.07	9.63	0.113	7.87	£249,865.80
Monkey puzzle	1307	110.02	6.53	6.1	0.143	15.77	£726,534.56
European hornbeam	1307	38.08	3.83	3.67	0.115	6.95	£122,603.48
Deodar cedar	1307	260.91	9.04	8.04	0.318	74.48	£1,668,893.75
Dogwood	1307	8.6	2.76	2.72	0.043	2.51	£53,323.29
Flowering dogwood	1307	65.68	8.33	8.05	0.136	7.89	£123,952.94
Thorny elaeagnus	1307	36.07	6.55	6.39	0.036	2.69	£52,691.73
Ash spp	1307	5.6	1.34	1.33	0.009	0.79	£64,634.53
English walnut	1307	29.9	6.01	5.87	0.087	3.68	£69,177.35
Japanese mahonia	1307	17.25	4.31	4.23	0.011	0.95	£42,658.76
Saucer magnolia	1307	19.19	3.88	3.79	0.019	1.27	£73,280.46
Nothofagus	1307	22.17	2.02	2	0.008	0.59	£14,219.81
Black poplar	1307	787.26	18.17	16.39	0.183	13.2	£2,779,304.42
Cherry spp	1307	40.37		-11.1			£0.00
Common plum	1307	17.19	3.47	3.13	0.012	0.96	£29,221.47
Flowering plum	1307	3.83	1.66	1.63	0.006	0.49	£42,658.76
Black locust	1307	381.55	17.73	16.24	0.319	17.18	£1,152,809.03
Mountain ash	1307	20.86	4.88	4.78	0.06	4.75	£64,634.53
Common lilac	1307	4.33	1.58	1.55	0.005	0.49	£64,634.53
Small leaf lime	1307	1504.68	36.48	31.6	0.989	74.08	£6,688,444.68
Large leaf lime	1307	910.89	18.24	16.2	1.343	79.46	£3,985,805.25
Viburnum	1307	25.53	5.36	5.25	0.024	1.77	£73,698.42
Fir	654	30.23	2.91	2.79	0.012	1.72	£49,105.47
Spanish fir	654	15.73	2.29	2.23	0.034	4.82	£23,311.39
Acacia	654	60.6	3.9	3.76	0.025	6.16	£132,010.83
Red horsechestnut	654	12.85	1.62	1.57	0.073	5.37	£43,089.90
European alder	654	108.76	8.21	7.14	0.056	4.05	£287,182.08
Eastern service berry	654	7.87	2.09	2.05	0.013	0.99	£32,317.26
Silver birch	654	108.74	9.02	8.59	0.152	9.01	£342,162.04
Buddleja	654	15.1	3.01	2.95	0.005	0.37	£29,707.33
Orange	654	15.76	3.05	2.98	0.009	1.07	£11,656.02

Species	Number of trees	Carbon (mt)	Gross Seq (mt/yr)	Net Seq (mt/yr)	Leaf Area (km2)	Leaf Biomass (mt)	Value
Smoketree	654	18.55	3.4	3.32	0.032	2.37	£27,035.43
Quince	654	3.37	1.05	1.03	0.004	0.33	£21,329.71
Beech spp	654	2.63	1.11	1.09	0.001	0.07	£32,317.26
Fuchsia	654	10.53	1.44	1.41	0.023	1.68	£28,612.33
Juniper	654	57.15	3.64	3.42	0.035	9.84	£262,705.82
Black walnut	654	201.52	10.47	9.68	0.496	39.72	£816,534.00
Sweetgum	654	6.69	1.23	1.2	0.027	1.26	£21,329.71
Southern magnolia	654	41.95	4.53	4.35	0.055	7.44	£76,283.30
Medlar	654	29.13	3.82	3.7	0.023	1.72	£39,863.58
Mountain pine	654	9.21	0.81	0.79	0.008	0.79	£53,503.26
Serbian spruce	654	30.9	3.37	3.24	0.019	3.52	£44,691.86
Sitka spruce	654	2841.64	27.76	21.44	1.302	220.95	£7,942,402.22
Sycamore	654	98.19	5.34	5.11	0.106	4.87	£273,729.63
Almond	654	4.06	1.29	1.26	0.009	0.87	£21,329.71
Portugal laurel	654	77.47	7.33	7.01	0.01	0.76	£166,996.04
Pear	654	30.82	3.98	3.85	0.027	2.03	£60,399.57
Sessile oak	654	19.09	2.72	2.18	0.06	5.49	£25,397.22
Northern red oak	654	102.45	5.71	5.47	0.133	10.6	£260,043.15
Rhodora	654	7.33	1.07	1.06	0.013	2.55	£28,612.33
Willow spp	654	66.71	6.17	5.9	0.041	2.54	£183,006.34
Lilac	654	6.27	1.84	1.81	0.012	1.13	£40,396.91
Lime spp	654	1178.46	18.1	13.64	0.829	38.56	£6,005,078.47
Gorse	654	1.46	0.47	0.46	0.005	0.37	£32,317.26
Yucca	654	0.58	0.03	0.02	0.01	0.72	£0.00

Appendix V. Notes on UFORE Methodology

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[21]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models[22]. 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[23] [24] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[25].

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information[26] [27].

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

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21 Nowak 1994

22 Baldocchi 1987, 1988

23 Bidwell and Fraser 1972

24 Lovett 1994

25 Zinke 1967

26 Hollis 2007

27 Rogers et al (in Press)

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