TORBAY COUNCIL

Torbay's Urban Forest

Assessing Urban Forest Effects and Values II

Technical Report

2022

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In addition we would also like to thank our supporters and project volunteers:

We would like to say a huge thank you to the time and support from our wonderful team of volunteers. This project would not have been possible without your commitment.

Finally, we wish to thank all landowners and members of the public who allowed access to their properties for the collection of the crucial field data.

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Foreword

by Greg Ina -

Executive Vice President, The Davey Institute

What today is a $1.3 billion tree care company in North America has its roots in the English town of Torbay.

John Davey, the Father of Tree Surgery, studied horticulture and landscape gardening in Torbay, England, before embarking on an historic journey. Davey, who worked on farms in Stawley and Ashbrittle in Somerset as a young man, made the short trip to Torbay in 1867. There, at the age of 21, Davey entered a six-year apprenticeship in the south of England where he learned greenhouse management, horticulture and finally floriculture to add to his agricultural expertise.

The skills he acquired on the shores of the English Channel would set his sights on a further shore – America.

Davey's knowledge of plant care gained in England undoubtedly contributed to the genesis of his concepts of tree care and tree surgery. These concepts Davey tested in the U.S., after emigrating there in 1873. Once there, Davey began experimenting with his new theory that trees could be saved by curative processes. It was there he conceived – and proved – the idea that a system of methods and treatment could be devised to save innumerable trees that were being lost unnecessarily.

Davey's ideas led to the founding of North America's oldest and largest tree care business, The Davey Tree Expert Company, in 1880. And later, in 1901, he would publish The Tree Doctor, his magnum opus on the practice of tree surgery which further contributed to the growth of the tree care industry.

John Davey, founder of The Davey Tree Expert Company

Davey Tree has become known for many achievements in the science of tree and plant care in the past 142 years. Among them is our work in collaboration with the U.S. Forest Service and other partners, on the development of the i-Tree® suite of software tools. This state-of-the-art, peer-reviewed software suite helps communities improve the management of their urban forests and strengthen their advocacy for them. i-Tree does this by helping people understand the ecological services trees provide.

It's no surprise Davey's legacy contributed to the creation of a software tool that measures and quantifies the benefits of trees. Now, that tool plays an important role in helping assess the urban forest where John Davey first learned the value of caring for our natural environment. We are proud to see John's work returning to its roots.

Executive Summary

Torbay have undertaken a second i-Tree Eco Sample survey, little over a decade after the original study. This project reports on the current structure of the urban forest of Torbay, and the ecosystem services which it affords to the area. It has been compared to the original data from 2010 to see how the urban forest has changed over time.

- Torbay's urban forest is comprised of 458,800 trees, covering 18.2% of Torbay.

- In comparison with the previous study undertaken in 2010, tree numbers have reduced, however canopy cover across Torbay has increased by 6.4%.

- Total annual benefits of trees are valued at £6,320,00 per year. Pollution removal and avoided run-off have increased since 2010, however carbon sequestration has decreased.

- Grasses and herbaceous plants account for 48.8% of the ground cover in Torbay, and a further 10.8% is shrub cover.

- The cost to replace the urban forest would be upwards of £306 million.

- The trees are estimated to be worth £4.1 billion in amenity value (CAVAT) and green spaces are estimated to be worth £45 million in recreational value (ORVal).

- The most common tree species is *Fraxinus Excelsior*, which represents 14% of all trees in the urban forest. The vast majority of these trees are in poor or critical condition due to the effects of Ash Dieback.

- Ash dieback could affect over 83,000 trees with an estimated replacement cost of £27.5 million.

- A number of other green infrastructure aspects have been valued along side the trees, including shrubs, grasslands, soils, and seagrass.

Headline Figures

Structure and Composition Headline Figures

	2022 Study			2010 Study
Number of Trees (estimate)	459,000			692,000
Tree Density (trees/hectare)	71			109
Tree Canopy Cover	18.2%			11.8%
Shrub Cover	10.8%			6.4%
Other Green Infrastructure Cover	48.8%			-
Seagrass Cover	52.2 ha			-
Most Common Tree Species	*Fraxinus excelcior* 14.1%	*Acer pseudoplatanus* 10.8%	*Corylus avellana* 7.6%	*Cuprocyapris leylandii, Fraxinus excelcior, Acer pseudoplatanus*
Most Common Tree Genera	*Fraxinus* 18.1%	*Acer* 12.0%	*Quercus* 11.4%	-
Replacement Cost (CTLA)	£306 million			£371 million
Amenity Valuation (CAVAT)	£4.1 billion			-
Recreational Valuation (ORVal)	£44.5 million			-

N.B. Tree canopy cover, shrub cover and green infrastructure cover can overlap in some areas. Tree canopy refers to the area covered by the canopy of trees; shrub cover refers to the area of ground covered by shrubs and small trees under 3m tall; green infrastructure cover refers to land covered by other green infrastructure such as grass and herbaceous plants.

Ecosystem Services Provided by Trees Compared

	2010		2022		Difference
	Amount	Value	Amount	Value	
Carbon Storage (whole value)	154,000 tonnes	£140,000,000	172,000 tonnes	£156,000,000	18,000 tonnes
Annual Carbon Sequestration	5,680 tonnes	£5,170,000	4,910 tonnes	£4,470,000	-770 tonnes
Annual Pollution Removal	57 tonnes	£1,300,000	67 tonnes	£1,210,000	10 tonnes
Annual Avoided Runoff	158,000 m^3	£520,000	195,000 m^3	£643,000	37,000 m^3

Other Ecosystem Services of the Urban Forest

Green Infrastructure	Benefit Quantified	Value
Shrubs	Pollution removal	£1.14 million /year
Grasslands	Carbon sequestration	£256,000 /year
Soil	Carbon storage	£167 million (total)
Seagrass	Carbon storage	£5.72 million (total)

Reference Values Notes for Headline figures:

Number of Trees: The sample inventory figures are estimated by extrapolation from the sample plots. For further details see the methodology section.

Canopy Cover: The area of ground covered by the leaves of trees and shrubs when viewed from above (not to be confused with leaf area which is the total surface area of leaves).

Replacement Cost: The cost of having to replace a tree with a similar tree using the Council of Tree and Landscape Appraisers (CTLA) methodology guidance from the Royal Institute of Chartered Surveyors.

Outdoor Recreation Valuation (ORVal): An online map-based application developed by the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter and DEFRA which permits the interpretation and analysis of benefits derived from accessible green spaces

Capital Asset Value for Amenity Trees (CAVAT): A valuation method with a similar basis to the CTLA Trunk Formula Method, but one developed in the UK to express a tree's relative contribution to public amenity and its prominence in the urban landscape. For i-Tree Eco studies the amended quick method is used.

Carbon Storage: The amount of carbon bound up in the above-ground and below-ground parts of woody vegetation.

Carbon Sequestration: The annual removal of carbon dioxide from the air by plants.

Carbon storage and sequestration values are calculated based on the CO_2 equivalent multiplied by BEIS figures for the non traded central estimate cost of carbon. This is currently £248 per metric ton for 2022.

Pollution Removal: This value is calculated based on the 2022 UK social damage costs for 'Road Transport Urban Large' and the US externality prices where UK figures are not available; £0.98427 per kg (carbon monoxide - USEC), £2.89 per kg (ozone - USEC), £11.973 per kg (nitrogen dioxide - UKSDC), £6.926 per kg (sulphur dioxide - UKSDC), £224.525 per kg (particulate matter less than 2.5 microns - UKSDC). USEC Values calculated using an exchange rate of $0.75 = £1.00.

Avoided Run-off: Based on the amount of water held in the tree canopy and re-evaporated after the rainfall event. The value is based on a volumetric charge of £3.29 per cubic metre.

Total Annual Benefits: Sum of the monetary values of carbon sequestration, pollution removal and avoided run-off.

Data was processed using iTree Eco Version 6.1.39

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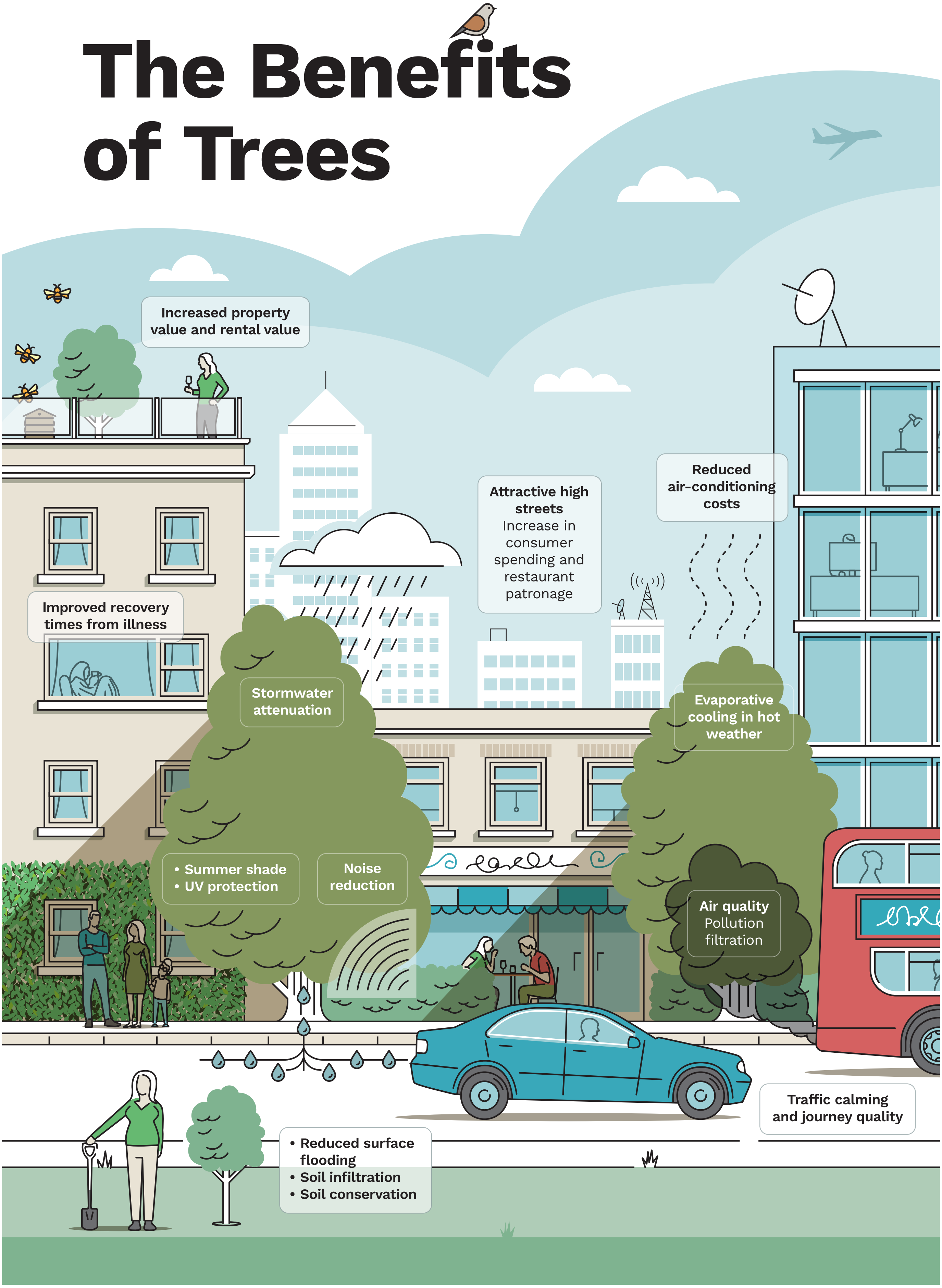
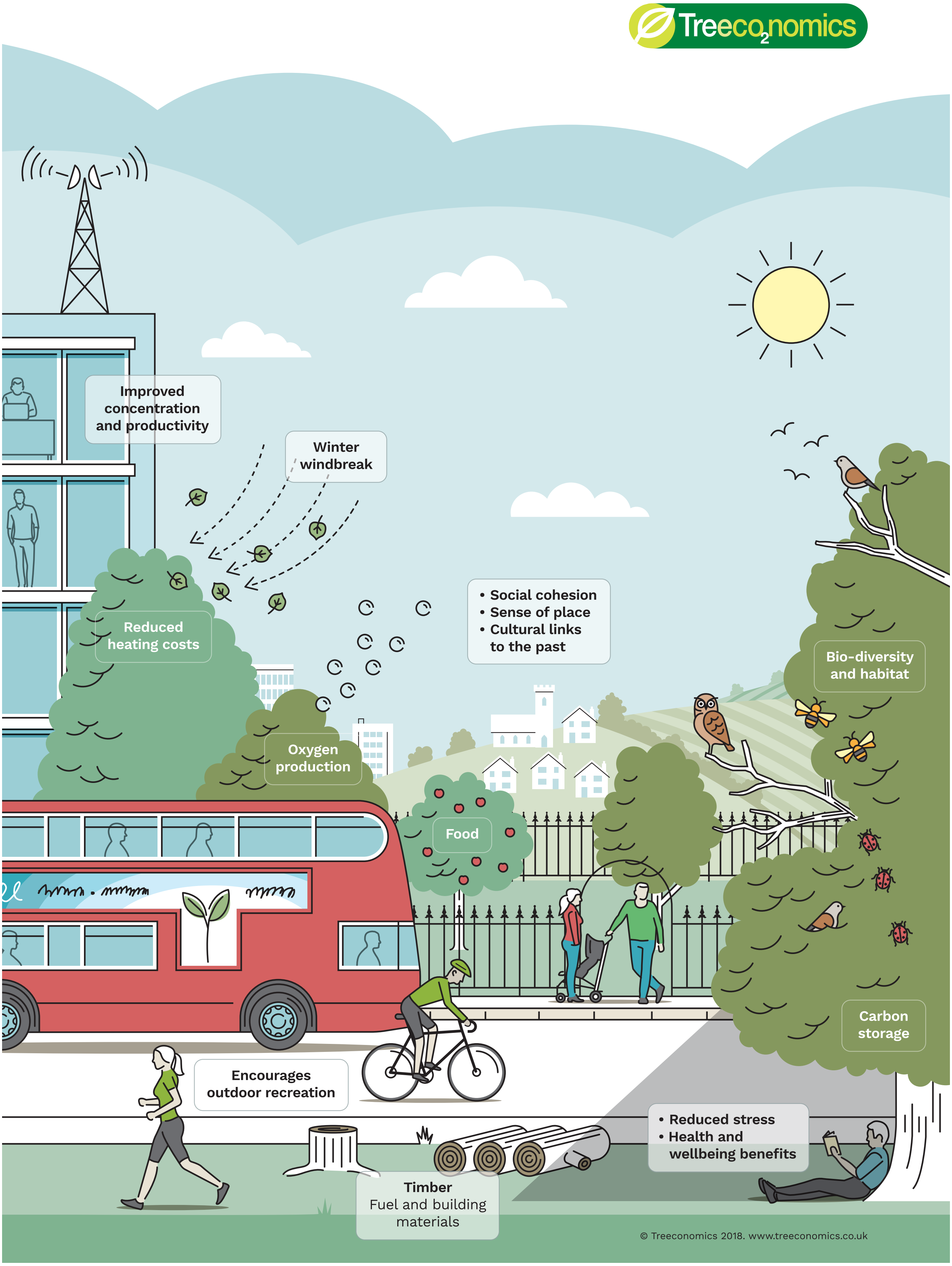
The Benefits of Trees





Treeco2nomics
Improved concentration and productivity
Winter windbreak
Reduced heating costs
Oxygen production
• Social cohesion
• Sense of place
• Cultural links to the past
Bio-diversity and habitat
Food
Carbon storage
Encourages outdoor recreation
Timber
Fuel and building materials
• Reduced stress
• Health and wellbeing benefits

Introduction and Background

Torbay, a borough in Devon, spans the towns of Torquay, Paignton and Brixham and sits on a natural harbour. It is a popular tourist destination as it has a mild climate and abounds in recreational activities, giving it the popular name 'The English Riviera'. Alongside the 22 miles of coastline, green infrastructure is well understood to contribute to the amenity of urban areas, and is a key aspect of Torbay.

In 2010, Torbay Council commissioned a 'first of its kind' survey of its tree population, in order to find out what kinds of trees it had, how many, and what these trees were giving back to the environment and to the people who live there. Just over ten years later, Torbay has repeated the study, with the objective to get a picture of how things have changed and to see how resilient its urban forest has become to climate change. This new valuation expands on the previous to provide a clearer overview of the whole urban forest.

The urban forest of Torbay comprises of a whole range of green infrastructure, and while trees may be the most obvious and most valuable, shrubs, grasslands, soils and seagrass all offer important contributions to the diversity and resilience of Torbay, by providing ecosystem services and amenity value.

The 2022 Torbay project was carried out as a partnership between Treeconomics, Torbay Council owned company SWISCo, tree specialists Hi-Line, and Forest Research. Fieldwork was completed by teams of volunteer tree wardens from across the region, Treeconomics and SWISCo. The resulting data has been analysed using 'i-Tree Eco', a software suite developed by the US Forest Service, to assess the structural value and environmental benefits of urban trees. Since the UK pilot in Torbay, many other councils have followed suit, and commissioned reports to value their own urban forests.

Report Scope

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

This report also acts to support the process of understanding and managing the urban forest after the initial study in 2010. In monitoring progress, management strategies can be assessed and amended (if required) in line with the findings of both this study and the previous.

The Torbay i-Tree Eco project aims to:

- Provide a snapshot of the urban forest as it stands at the time of the study.
- Illustrate the structure of Torbay's urban forest, including the species composition, diversity, and tree condition.
- Calculate the ecosystem service values provided by Torbay's urban forest and rank the importance of different trees in terms of ES provision using the i-Tree Eco software suite.
- Promote Torbay's urban forest to all, and emphasise the benefits it provides.
- Establish values that are a precursor to proper asset and risk management assessments and strategies.
- Conduct a risk analysis of the susceptibility of Torbay's urban forest to pests and diseases.
- Provide the opportunity to explore appropriate and effective methods of maintaining and improving current tree cover.
- Offer a comparison to the previous study undertaken in 2010.

This report can be used by:

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

This report does not include but may initiate other works such as:

- Further analysis of current and future management strategies pertaining to the range of green infrastructure assets discussed herein.
- A tree planting strategy.
- An Urban Forest Master Plan (or similar document) outlining a 'vision' for the urban forest going forward.

Methodology

To gather a collective representation of Torbay's urban forest across both public and privately held land, an i-Tree Eco (v6) plot-based assessment was undertaken. 250 randomly allocated plots of 0.04ha (400m^2) were set up, however 3 plots could not be accessed and were therefore not included in the analysis. This resulted in 1 plot every 26 ha. Random plot selection ensures that trees on both public and private land are included in the assessment.

Data was collected during the summer of 2021 and processed over subsequent months. Prices used to value ecosystem services are up to date at the time of report publication (2022).

The field data, combined with local pollution and meteorological data, was submitted to the i-Tree server, which then extrapolates the data to represent the whole of the study area and provide the outputs listed in Table 2 below.

Structure and Composition	Species diversity; Tree canopy cover; Age class; Leaf area; Ground cover types; % leaf area by species.
Ecosystem Services	Air pollution removal by trees for CO, NO_2, SO_2, O_3 and $PM_{2.5}$; % of total air pollution removed by trees; Current carbon storage; Carbon sequestration; Stormwater attenuation.
Structural and Functional Values	Replacement cost in £; Carbon storage value in £; Carbon sequestration value in £; Pollution removal value in £.
Additional Information	Potential insect and disease impacts; Oxygen production; Forest food production; UV Screening values.

Table 2: Study Outputs

The following information was recorded for each plot:

Plot Characteristics

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

Tree Characteristics

Tree species, shrub species, height (m), trunk diameter at breast height (DBH), canopy spread, the health and fullness of the canopy, light exposure to the crown, and safe useful life expectancy (LE). This data was collected by volunteers during 2021. Due to the requirements of the sampling method, 250 plots were created for the project. 247 plots were successfully surveyed. Amongst the data collected were tree species, diameter at breast height (DBH), tree height, tree condition and tree location. As the plots were randomly allocated to ensure a statistically significant distribution across Torbay, they fall on both public and private land. While most areas could be accessed with permission, some could not.

For a full review of the methodology see Rogers et al *(*2014). For more detail on the model calculations and field work see Appendix V.

Data Limitations

While Torbay's trees provide a plethora of benefits, the figures presented in this study represent only a portion of the total value of the borough's trees. i-Tree Eco does not quantify all of the services that trees provide; such as moderating local air temperatures, reducing noise pollution, improving health and well-being, providing wildlife habitat and, even, their ability to unite communities. Hence, the value of the ecosystem services provided in this report are a conservative estimate. Furthermore, the methodology has been devised to provide a statistically reliable representation of Torbay's urban forest in 2022. This report is concerned with the trees and shrubs within Torbay. This report should be used only for generalised information on the urban forest structure, function, and value. Where detailed information for a specific area (such as an individual park, street or ward) is required, further detailed survey work should be carried out.

Methods of assessing the value of other aspects of the urban forest, including grasslands, soil, and Torbay's seagrass involve value transfer methods, and therefore are a rough estimate which should be noted with caution.

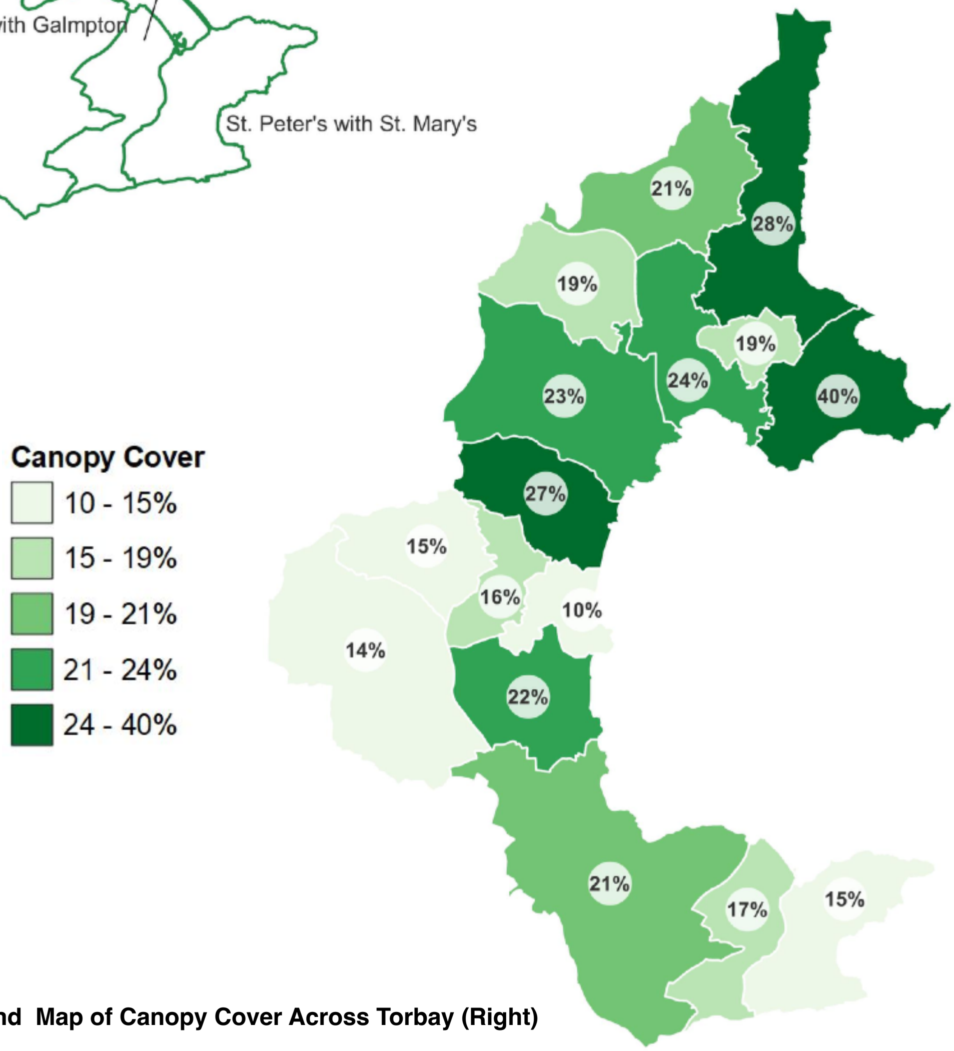


Figure 1: Map of Wards in Torbay (Top) and Map of Canopy Cover Across Torbay (Right)

i-Tree Eco Results - The Structural Resource

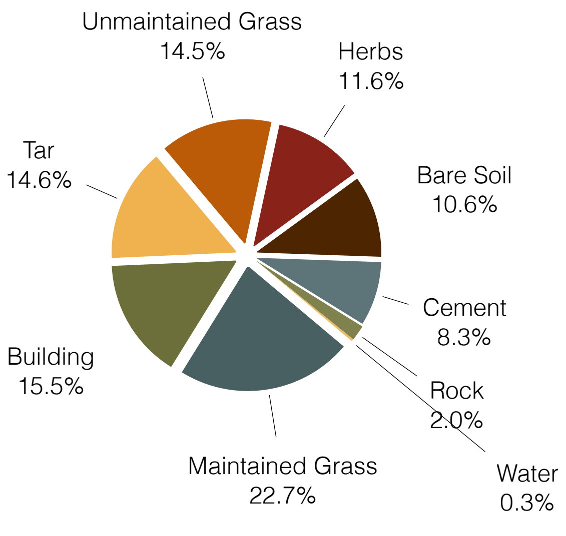


Figure 2: Ground cover types within plots.

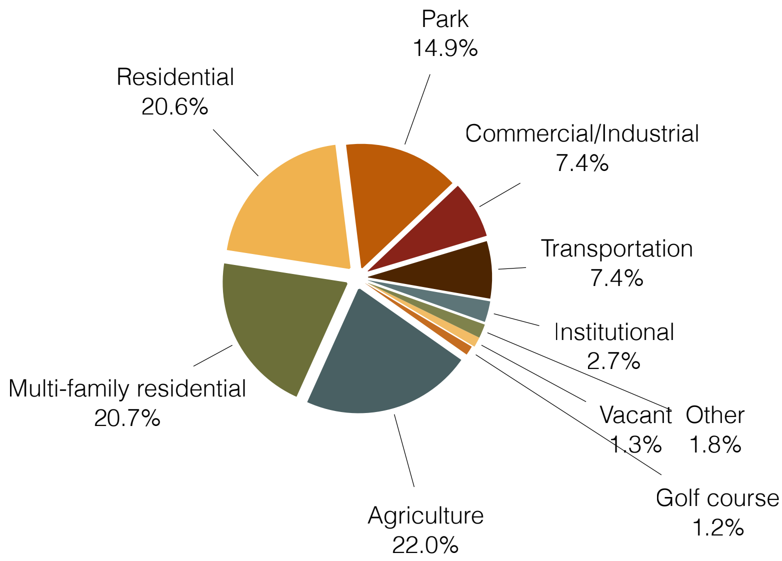


Figure 3: Land use types within plots.

Ground Cover

Within Torbay the most common ground cover types are grasses, buildings, tar and herbaceous plants. Impermeable surfaces account for 40% of ground cover.

Approximately 18.2% of Torbay is under tree canopy cover, with 10.8% under shrub cover (note that shrubs are also present under tree cover and so these figures 'overlap'). The survey also showed that a further 14.9% of land within the plots could (in theory) be planted with trees.

Utilising available space to increase the tree canopy cover is one way to contribute towards reduced air and noise pollution, and increased carbon sequestration.

60% of Torbay's area is made up of green space, 14% of which are parks.

Land Use

The surveyed plots indicate that in Torbay over 41% of land used for housing. Agriculture covers 22% of land use, and parkland accounts for 14%.

Figure 3 above shows the distribution of land use across Torbay.

Species Richness

Richness refers to the number of species identified across the study. In total, 62 species and 53 genera were recorded in the survey.

Torbay has an estimated tree population of 458,800 trees (72 trees per hectare). The ten most common species account for 65% of the total population.

The three most common species are *Fraxinus excelsior* at 14%, *Acer pseudoplatanus* at 11%, and *Corylus avellana* at 8% (figure 7 below). The most common genera are *Fraxinus* (18%), *Acer* (12%) and *Quercus* (11%) (figure 8 below).

Species richness in Torbay is fairly high, given the areas size and coastal setting.

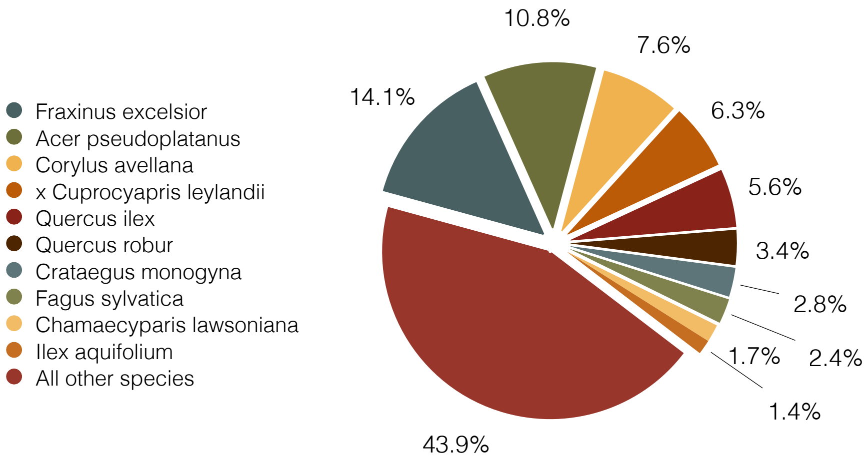
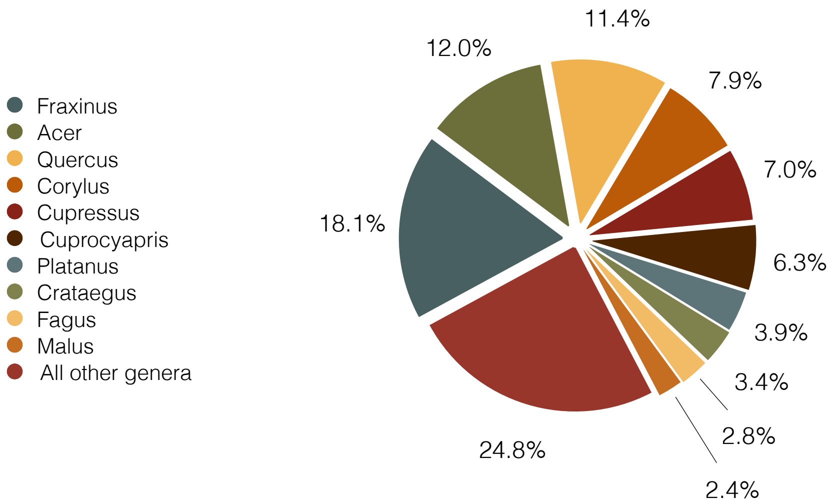


Figure 4: Top 10 most common species (above) and genera (below).



Species Evenness

Evenness refers to the spread of species across the population and how well each species is represented. A poor level of evenness indicates a reliance on just a few species. It is encouraged that no single species should represent more than 10% of any population, no genus should represent more than 20%, and no family should represent more than 30%.

Leaf area is a good indicator of evenness as it is a major factor in the delivery of ecosystem services.

In Torbay the most dominant species are *Fraxinus excelcior*, *Acer pseudoplatanus* and *Quercus ilex*. The most dominant genera are *Quercus*, *Fraxinus* and *Acer*.

The two most common species account for 14.1% and 10.8% respectively. This may compromise the resilience of Torbay's urban forest, especially since the most common species is *Fraxinus excelsior* (and the most common genus is *Fraxinus*) which is currently at risk from Ash Dieback disease.

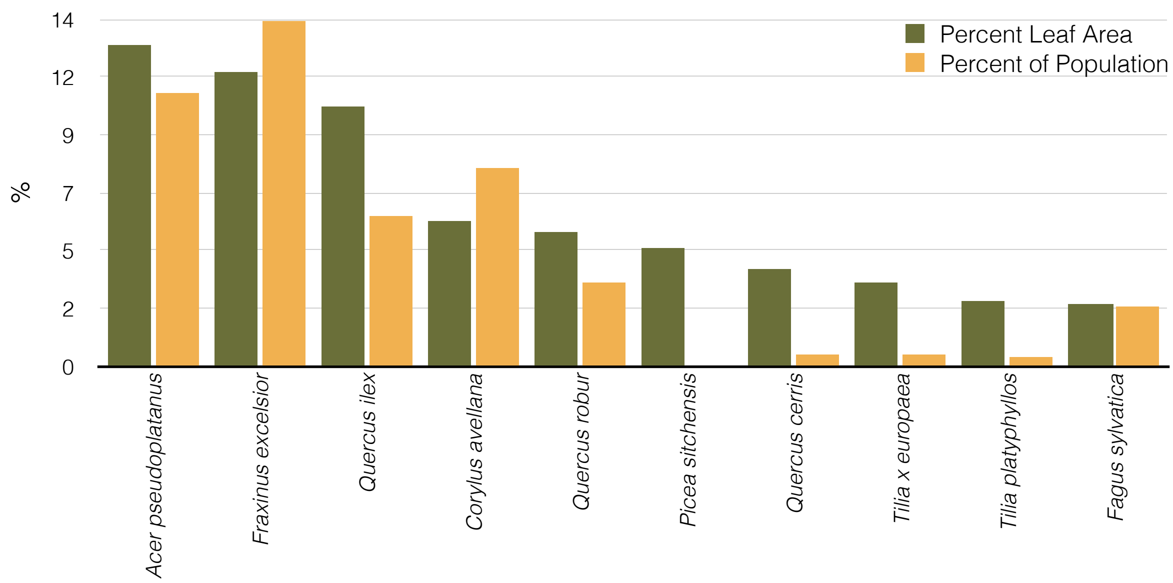
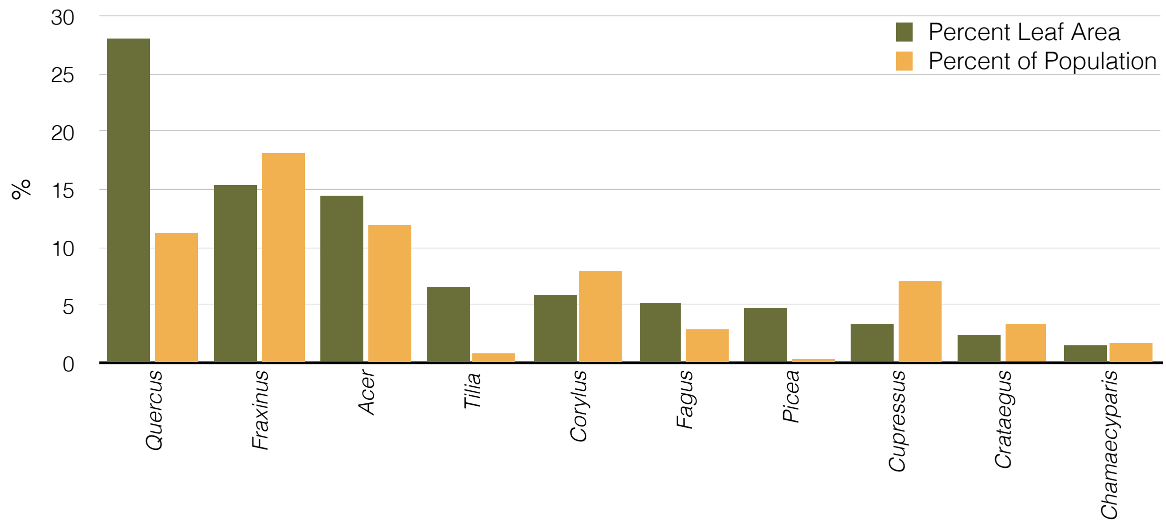


Figure 5: Top 10 most important species (above) and genera (below) for leaf area.



Tree Structure

Larger trees have a greater functional value and provide increased benefits (details of functional value and the resulting benefits are discussed later). It has been estimated in previous studies[1] 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 15 cm tree.[2]

Size class distribution is also an important factor in managing a sustainable tree population, as this will ensure that there are enough young trees to replace those older specimens that are eventually lost through old age or disease (Figure 6 below).

There are relatively few trees in Torbay in the lowest size category between 7 – 15cm DBH; the 'ideal' target is 40-60%. This reflects recent management works which have thinned areas of woodland to promote understory growth, and the higher mortality rate of young trees in urban environments. Over 56% of trees are between 15-45cm DBH, and represent semi-mature and mature trees. Torbay has protected their maturing trees, and 11.4% of the trees are over 60cm DBH.

"Most regions in England only have 10-20% of trees with a DBH that is greater than 30cm"
(Trees in Towns II)

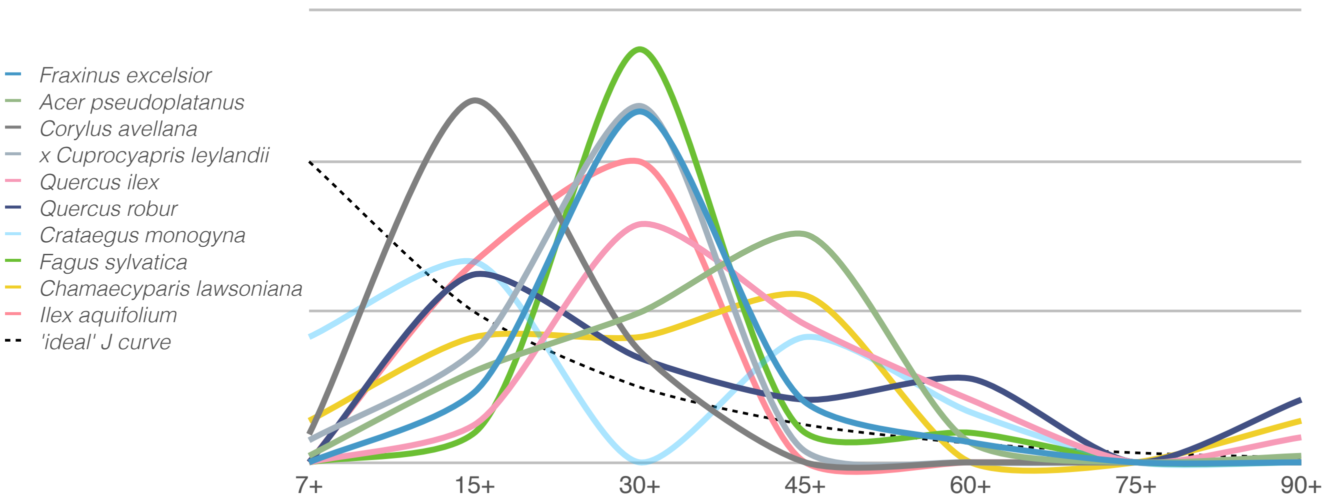


Figure 6: Spread of size classes amongst the top ten species, showing comparison to 'ideal' J-curve
'ideal' J-curve values reduce by half for each increase in DBH class

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

[2] Hand and Doick, 2019

Biodiversity of the Urban Forest

Biodiversity is important because it provides a wide range of indirect benefits to humans, however, challenges exist in valuing it because it is difficult to identify and measure the passive, non-use values of biodiversity.[3]

The diversity of species within Torbay (both native and non-native) will influence how resilient the tree population will be to future changes, such as minimising the overall impact of exotic pests, diseases and climate change.

A diverse treescape is better able to serve as a habitat for a wide range of creatures, and native trees are important as they are better suited to support other native species.

Unfortunately, many native species are not able to thrive in the artificial environments of our landscaped areas, and the effects of climate change will exacerbate the situation,[4] therefore non-native species could become increasingly important for the delivery of benefits in Torbay.

Species	Scientific name	Total	Beetles	Flies	True bugs	Wasps & sawflys	Moths & butterflies	Other
Willow (3 spp)	*Salix* (3 spp.)	450	64	34	77	104	162	9
Oak (2 spp)	*Quercus* (2 spp.)	423	67	7	81	70	189	9
Birch (4 spp)	*Betula* (4 spp.)	334	57	5	42	42	179	9
Hawthorn	*Crataegus monogyna*	209	20	5	40	12	124	8
Poplar (3 spp)	*Populus* (3 spp.)	189	32	14	42	29	69	3
Scots Pine	*Pinus sylvestris*	172	87	2	25	11	41	6
Blackthorn	*Prunus spinosa*	153	13	2	29	7	91	11
Common Alder	*Alnus glutinosa*	141	16	3	32	21	60	9
Elm (2 spp)	*Ulmus* (2 spp.)	124	15	4	33	6	55	11
Hazel	*Corylus avellana*	106	18	7	19	8	48	6
Beech	*Fagus sylvatica*	98	34	6	11	2	41	4
Norway Spruce	*Picea abies*	70	11	3	23	10	22	1
Ash	*Fraxinus excelsior*	68	1	9	17	7	25	9
Rowan	*Sorbus aucuparia*	58	8	3	6	6	33	2
Lime (4 spp)	*Tilia* (4 spp.)	57	3	5	14	2	25	8
Field Maple	*Acer campestre*	51	2	5	12	2	24	6
Hornbeam	*Carpinus betulus*	51	5	3	11	2	28	2
Sycamore	*Acer pseudoplatanus*	43	2	3	11	2	20	5
European Larch	*Larix decidua*	38	6	1	9	5	16	1
Holly	*Ilex aquifolium*	10	4	1	2	0	3	0
Horse Chestnut	*Aesculus hippocastanun*	9	0	0	5	0	2	2
Common Walnut	*Juglans regia*	7	0	0	2	0	2	3
Yew	*Taxus baccata*	6	0	1	1	0	3	1
Holm Oak	*Quercus ilex*	5	0	0	1	0	4	0
False acacia	*Robinia pseudoacacia*	2	0	0	1	1	0	0

Table 3: The number of species of insects associated with British trees: a Re-analysis (Kennedy and Southwood)

3 Nunes et al, 2001

4 Gill et al 2007

Species Origin

Figure 7 (below) shows percentages for each of the four continents from which the 91 species found in the survey originate. More than half (60.3%) of the species are of European origin, and most of these are also native to Britain.

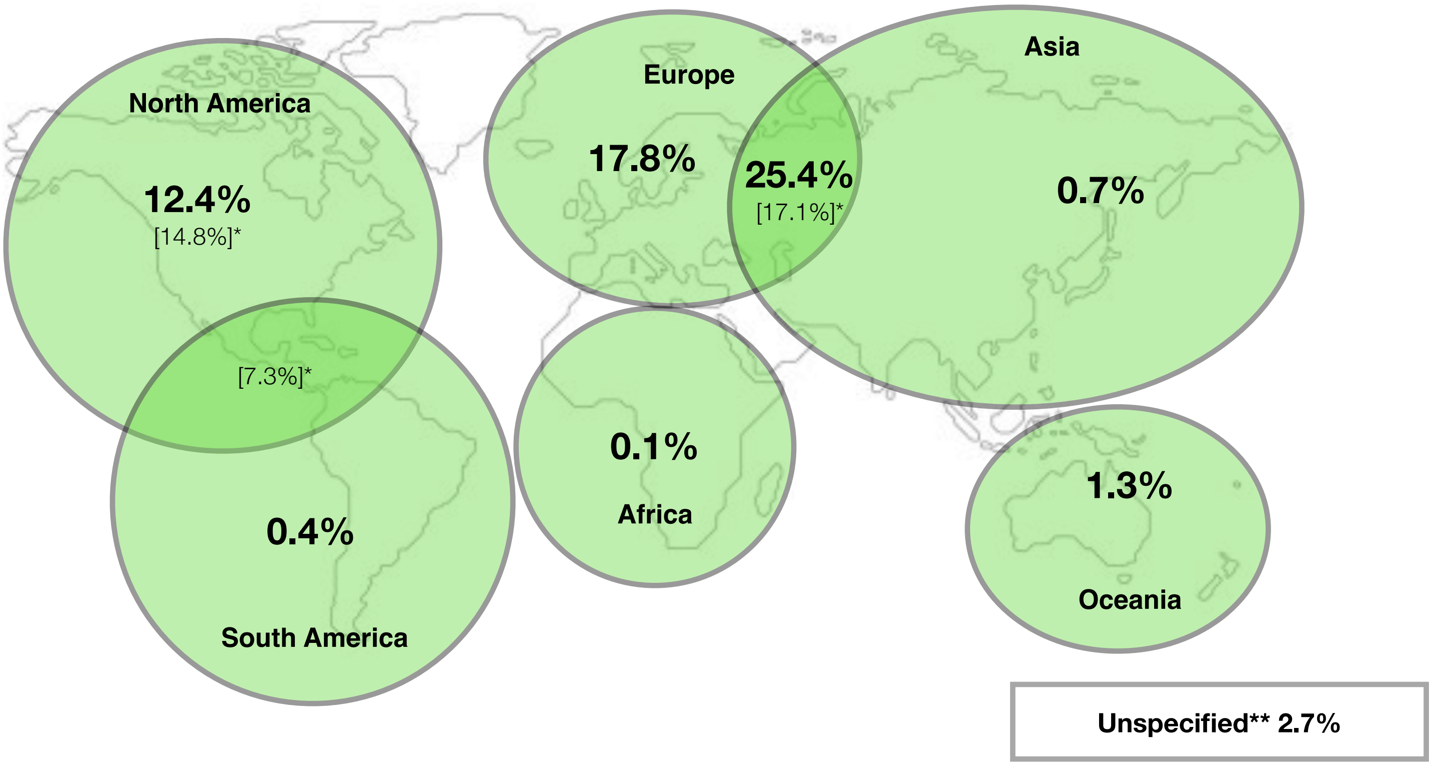


Figure 7: Species origins

NB. Values with [ ]* indicate species which originate from that continent pus another with which there is no intersection.

**Species origin is unknown or species may be hybridised and therefore not 'native' to any given location.

"It is that range of biodiversity that we must care for - the whole thing - rather than just one or two stars."

~ David Attenborough

i-Tree Eco Results- Ecosystem Services Resource

Air Pollution Removal

The problems caused by poor air quality 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 (thereby lowering ozone levels), directly removing pollutants from the air, absorbing them through the leaf surfaces and by intercepting particulate matter (eg: smoke, pollen, PM_{10} and $PM_{2.5}$). They can also indirectly reduce energy consumption in buildings, reducing air pollutant emissions from power plants.

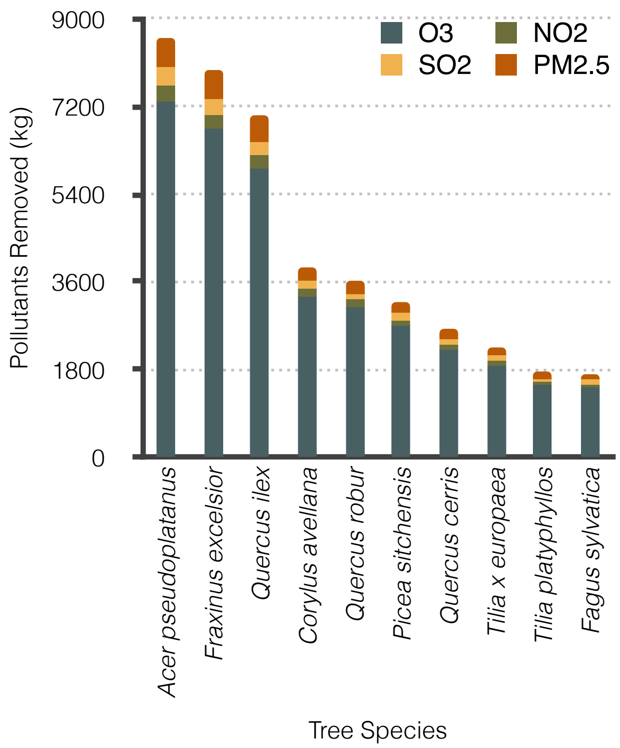
As well as reducing ozone levels, it is well known that a number of tree species also produce the volatile organic compounds (VOCs) that lead to ozone production in the atmosphere. The i-Tree software accounts for both reduction and production of VOC's, and the overall effect of Torbay's trees is to reduce ozone through evaporative cooling.[5]

Total pollution removal in Torbay by trees is approximately 67.3 tonnes per year which equates to 10.5 kg/ha/yr.

Pollutant	Tonnes removed by trees per year	Value
Carbon monoxide (CO)	0.3	£ 360 (USEC)
Nitrogen dioxide (NO_2)	2.5	£30,060 (UKSDC)
Ozone (O_3)	56.7	£163,700 (USEC)
Particulates (<$PM_{2.5}$)	5.1	£1,140,000 (UKSDC)
Sulphur dioxide (SO_2)	2.7	£18,380 (UKSDC)
Total	**67.3**	**£1,352,200**

Table 4: Quantity and value of the pollutants removed per-annum within Torbay. Valuation method's used are UK social damage cost (UKSDC) where they are available - where there are no UK figures, the US externality cost (USEC) is used as a substitution.

5 Nowak et al, 2000.



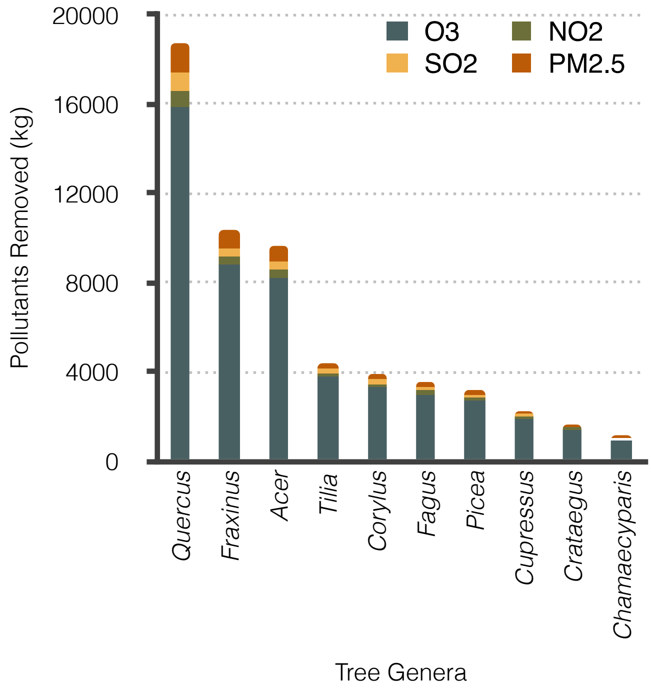


Figure 8. Annual Pollution Removal and Associated Value for the top 10 species (left) and genera (right).

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.[6] Furthermore, because filtering capacity is closely linked to leaf area it is generally the trees with larger canopy potential that provide the most benefits.

It is estimated that the trees and shrubs in Torbay collectively remove 115 metric tonnes of air pollution per year with an associated value of almost £2.5 million per year.

Of the trees, *Acer pseudoplatanus* removes the most pollution of any species, and the top 3 pollution removing species account for 35% of all pollution removal by trees. By genus, *Quercus* is the highest performing, removing 18.8 tonnes/yr, and the top 3 pollution removing genera account for 58% of all pollution removal by trees.

Torbay's trees remove over £1.35 million worth of pollutants from the atmosphere each year!

6 Escobedo and Nowak (2009)

Avoided Run-Off

Surface run-off can be a cause for concern in many areas as it can contribute to pollution in streams, wetlands, rivers, lakes, and oceans.

During precipitation events, a portion of the precipitation will be intercepted by vegetation (trees and shrubs) while a further portion reaches the ground. Precipitation that reaches the ground and does not infiltrate into the soil becomes surface run-off.[7]

Within an urban environment, the large extent of impervious surfaces increases the amount of run-off. However, trees are very effective at reducing this.[8] Trees intercept precipitation, whilst their root systems promote infiltration and storage in the soil.

The trees of Torbay help to reduce run-off by an estimated 195,000 cubic meters a year with an associated value of £643,000.

Acer pseudoplatanus intercepts the most water, removing 25,200 m^3 of water per year, a service worth £83,000 (Figure 8). This is due to its population and canopy size.

[7] Hirabayashi (2012).

[8] Trees in Hard Landscapes (2014)

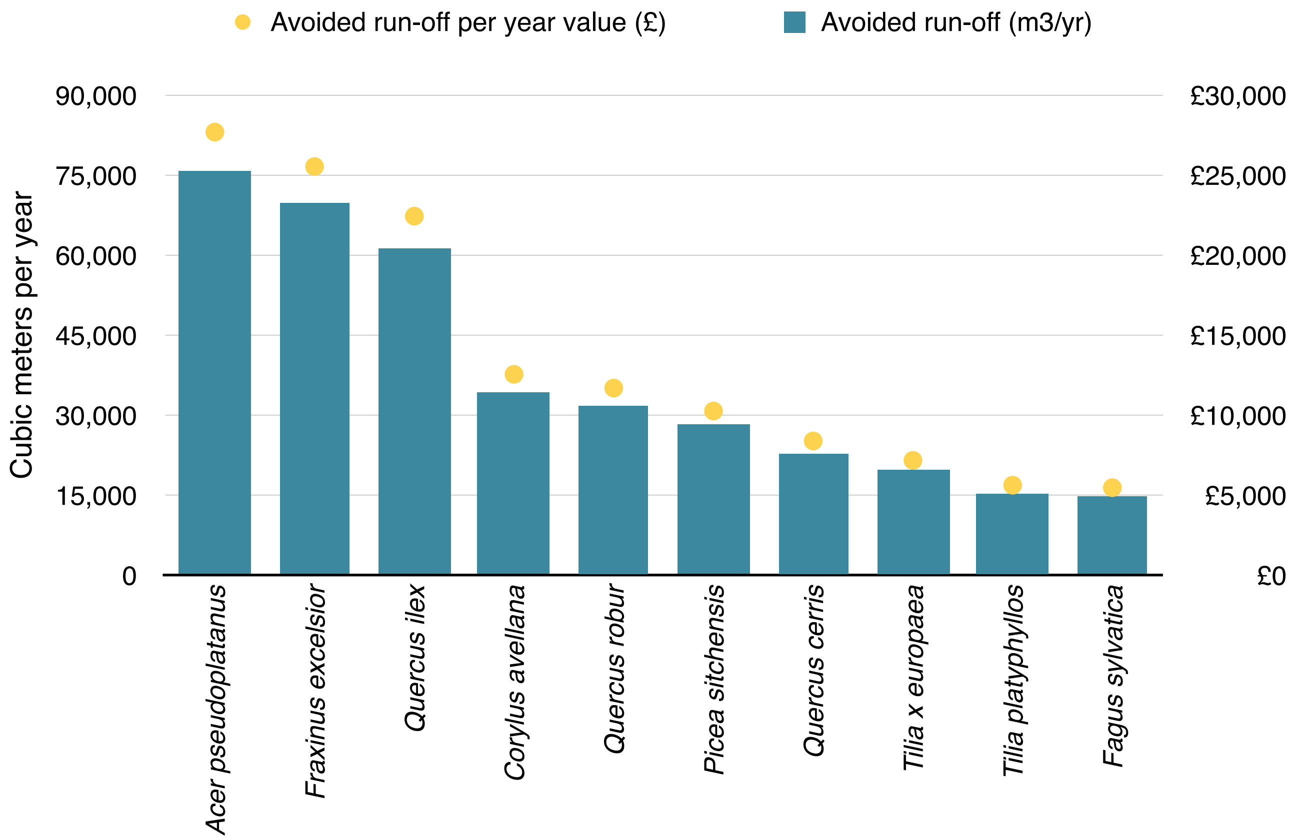
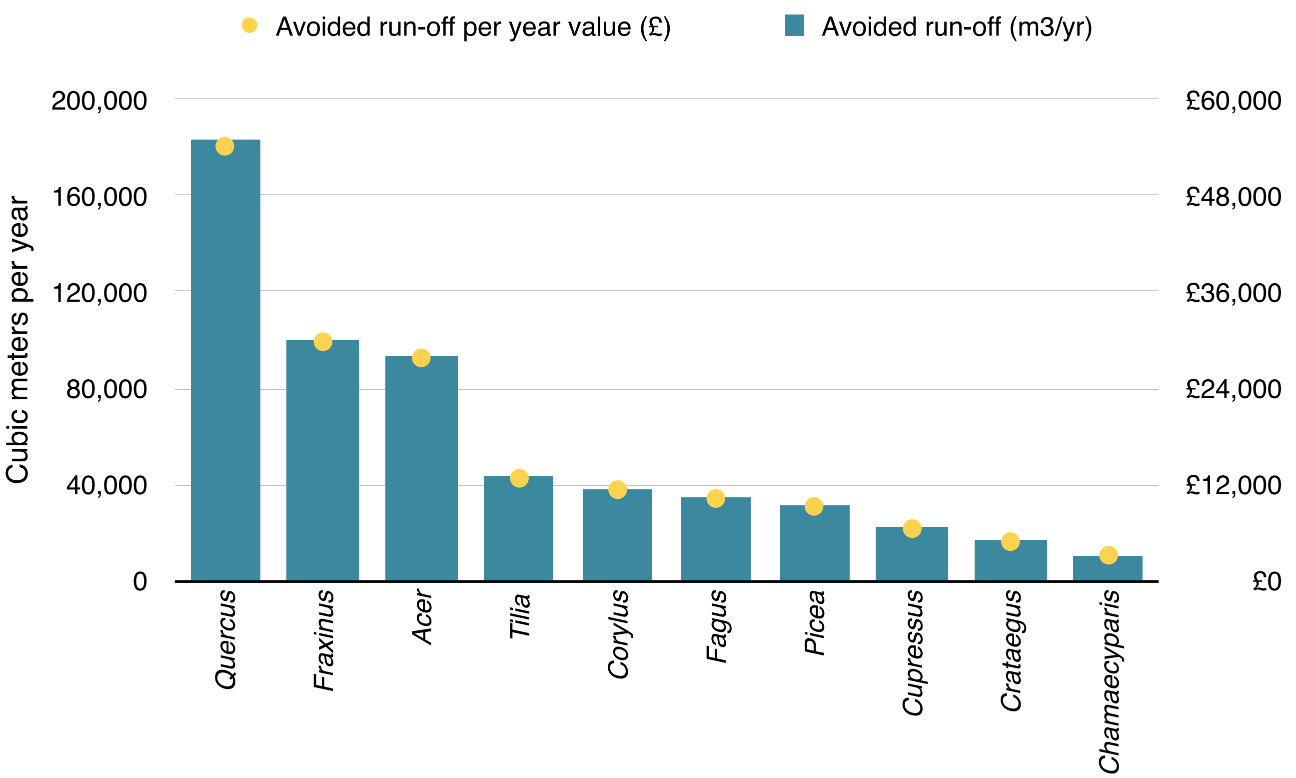
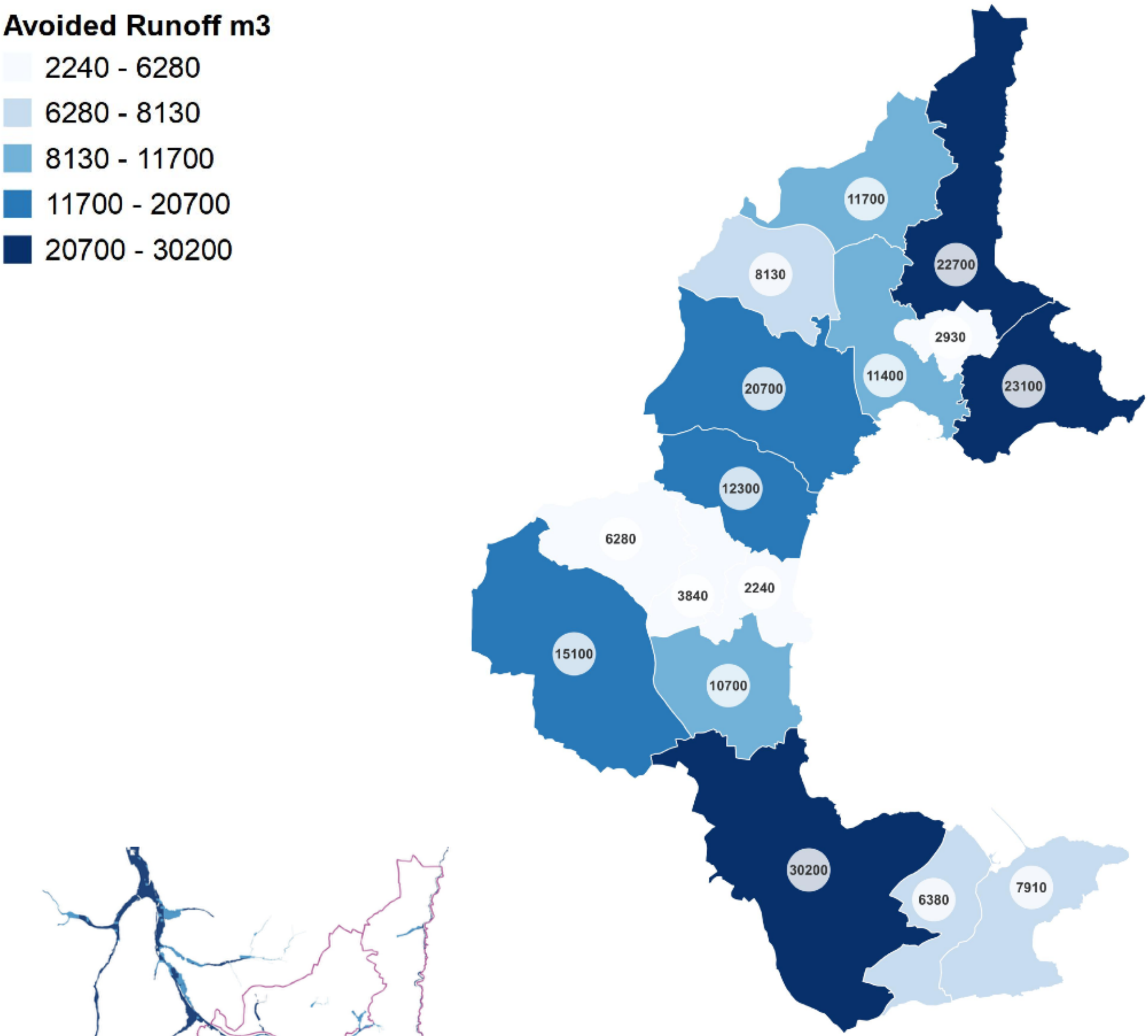


Figure 9: Stormwater attenuation for the top 10 most important species (above) and genera (below).




Avoided Runoff m3
2240 - 6280
6280 - 8130
8130 - 11700
11700 - 20700
20700 - 30200
11700
8130
22700
2930
11400
23100
20700
12300
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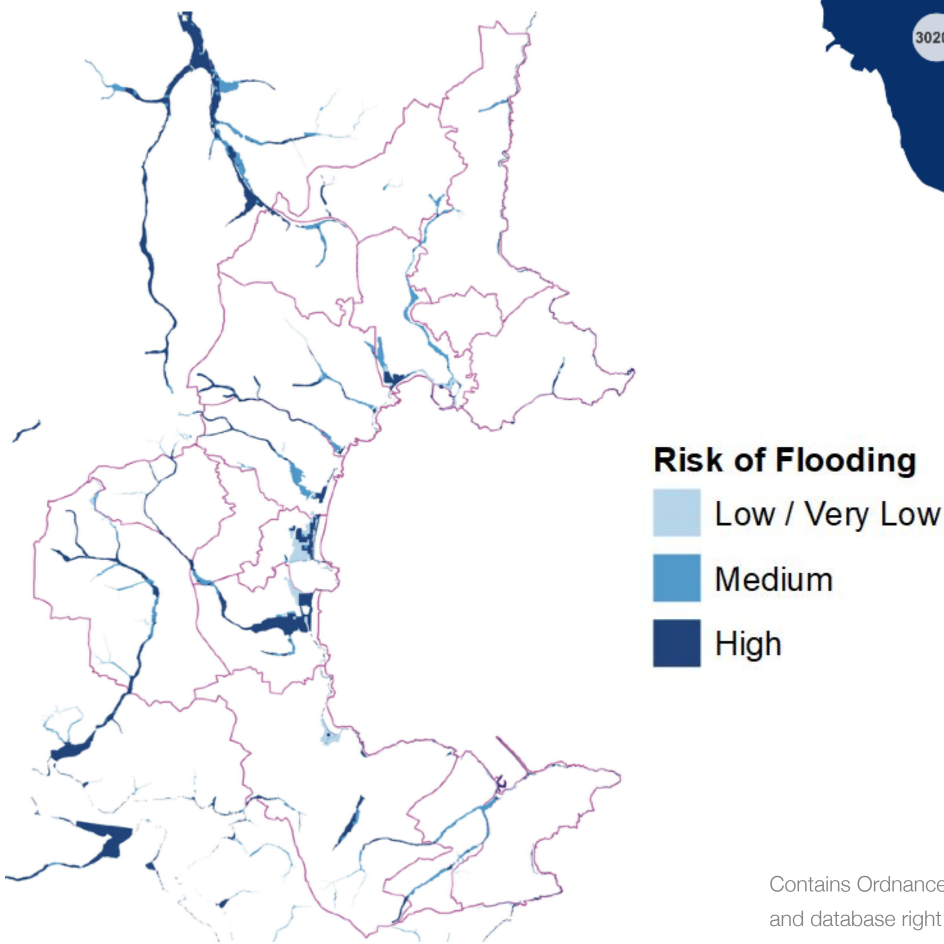
3840
2240
15100
10700
30200
6380
7910


Risk of Flooding
Low / Very Low
Medium
High

Carbon Storage and Sequestration

Trees can help mitigate climate change by sequestering atmospheric carbon. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots can store up carbon for decades or even centuries.[9]

An estimated 172,000 tonnes (47 t/ha) of carbon is stored in Torbay's trees with an estimated value of over £156 million (based on current carbon figures from BEIS).[10]

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 much of this carbon back into the atmosphere; the carbon storage figure 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. Larger trees store more carbon than smaller trees, but the rate of sequestration decreases with age. Utilising the timber 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 carbon sequestration of Torbay's trees is about 4,910 tonnes per year (approximately 770kg/ha/yr). This is valued at £4.5 million per year.

Trees also play an important role in protecting soils, which is one of the largest terrestrial sinks of carbon; they contain more carbon than the atmosphere and plants combined.[11]

9 Kuhns, 2008

10 BEIS (2022)

11 Ostle et al (2011).

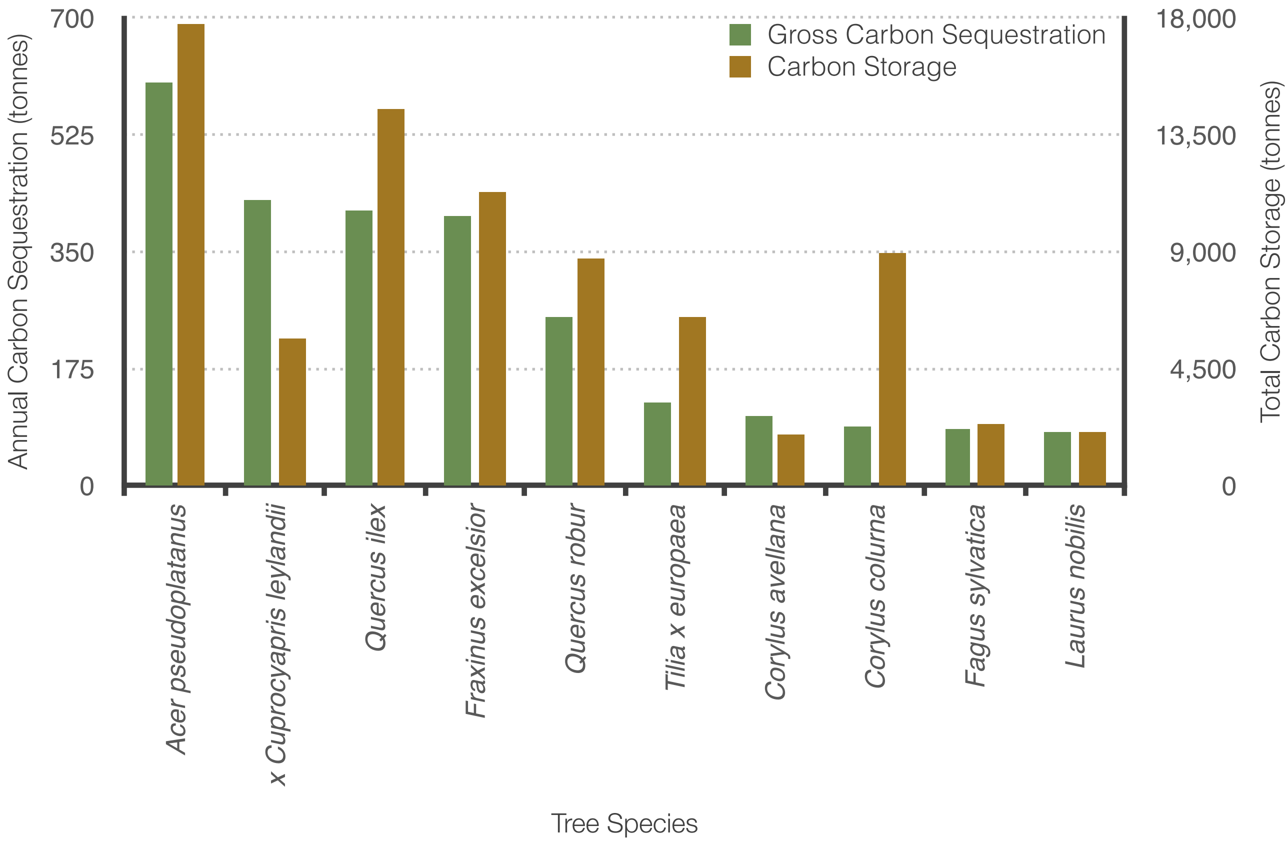
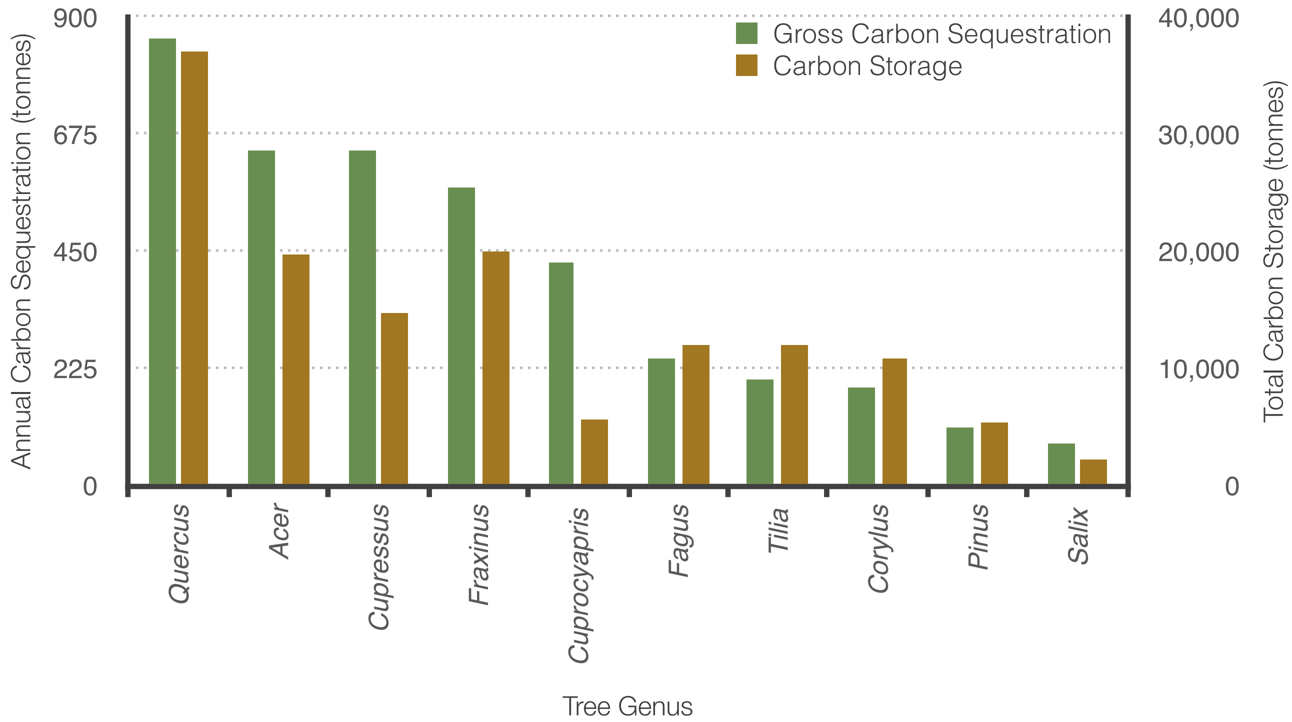
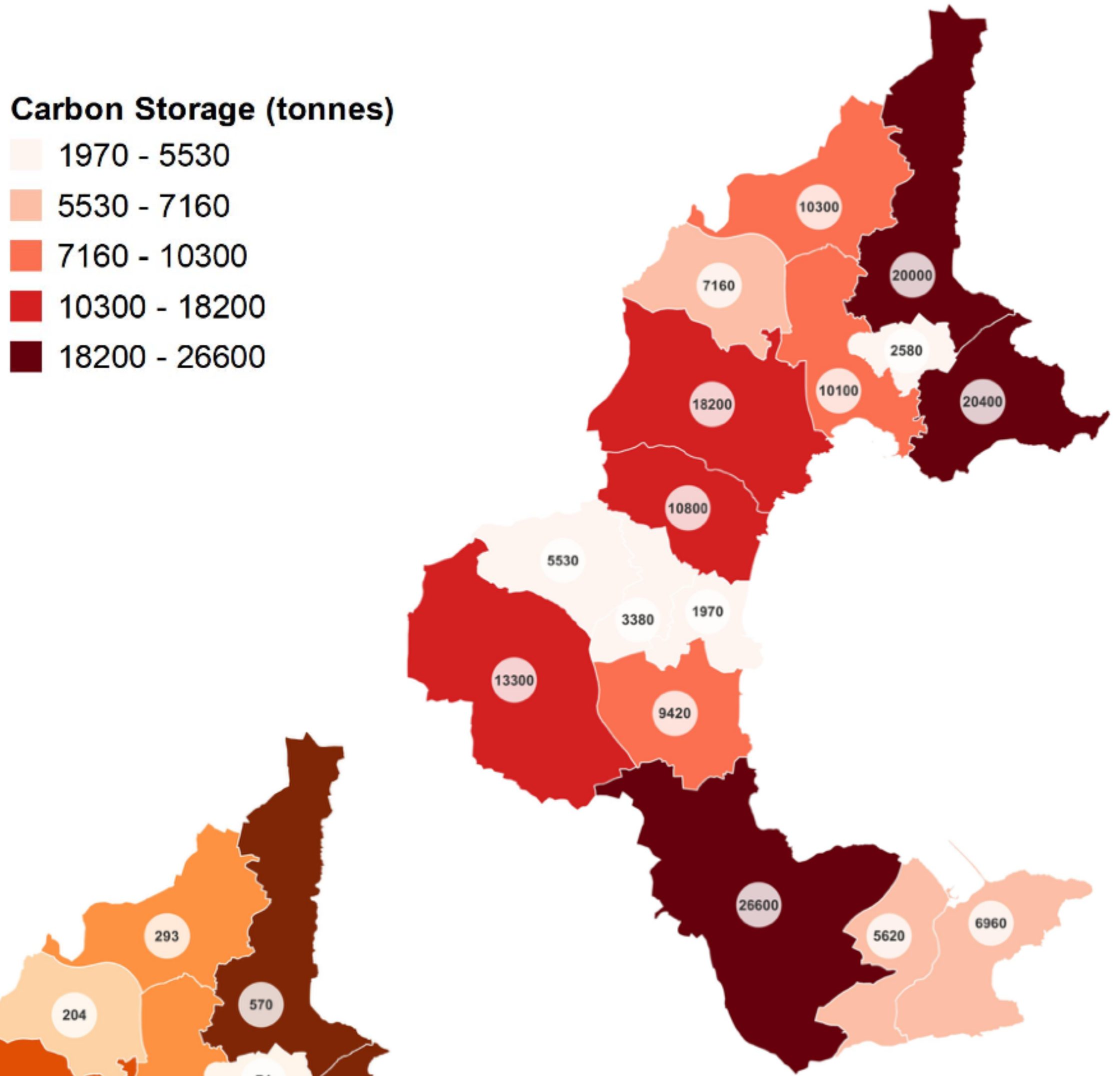
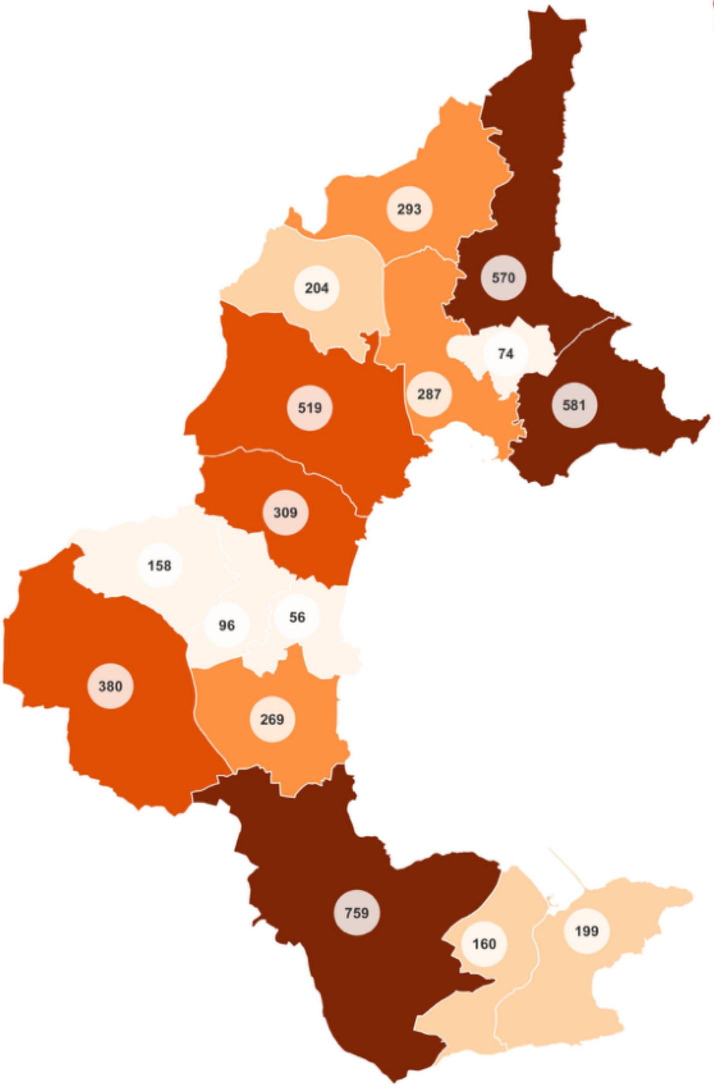


Figure 11: Ten most significant tree species (above) and genres (below) for carbon sequestration in Torbay.







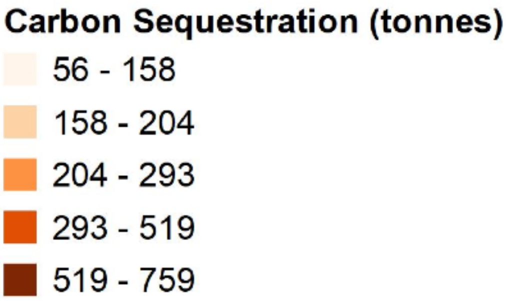


Figure 12: Map of Carbon Storage by Ward in Torbay (Top) and Map of Carbon Sequestration by ward Across Torbay (Left)

Benefits of Other Green Infrastructure

Shrubs

During the fieldwork for this project, data on the shrubs within each plot was collected. Unfortunately, i-Tree Eco does not have the capability to analyse this data in the same way it does the trees, however some aspects can be assessed. Shrubs often have a high amenity value, and can be planted in areas where trees may not have enough room to grow. They provide variety to the urban forest, and are particularly favourable in gardens where space may be limited.

Torbay's shrub cover is 10.8%. The leaf area of these shrubs is estimated to be 5,460 ha, and the biomass is approximately 4,760 tonnes. Like trees, shrubs also contribute to removing pollutants from the atmosphere. Torbay shrubs remove an estimated 38,680 kg of pollutants per year; a service valued at around £1.1 million.

The survey identified 135 species belonging to 83 genera; however, as noted in the methodology, trees below 7.5cm DBH and 3m high are included in the 'shrub' category. Of the 135 species identified, 42 species (of 29 genera) are species of tree, leaving 93 shrub species. The young trees account for 2,870 ha of leaf cover at present, however they have huge potential to provide far more ES in the future, particularly to sequester and store carbon. It is expected, however, that not all of these will survive to maturity, and this may be reduced in urban areas where trees may be poorly planted, or self-seeded trees are likely to be removed if they are badly placed. It is likely that shrub diversity is higher than identified, as gardens and parks may contain a large range in a small area, however further study of this resource would be required to fully understand its structure and benefits.

Grasslands

Grasses and herbaceous plants cover around 48.8% of Torbay, and are the most dominant ground cover by a significant margin. This vegetation cover is an important part of accessible green infrastructure, providing areas of recreation, margins along roads and private green spaces. It is important to consider these grassland areas, as they too have value, protect the soil, and are an important carbon sink.

Grassland Type	Area (ha)	% of Torbay's ground cover
Maintained Grass	1,147	22.7%
Unmaintained Grass	924	14.5%
Herbivorous Plants	740	11.6%
Total Grass Area	**2,811**	**48.8%**

Table 5. Ground cover for grassland types

It is likely that unmaintained grasslands and herbaceous plant will sequester more than maintained grass, however this difference is difficult to quantify.

Using an average sequestration value of 100 kg C/ha, it is estimated that 28 tonnes of carbon are sequestered per hectare, which equates to £256,000 worth of carbon sequestered every year by Torbay's grasslands. This carbon sequestered by grasses is stored directly in biomass or in soils.

Values for other ecosystem services provided by grasslands (such as pollution filtration, storm water, habitat and biodiversity) are more difficult to ascertain, and contributions of grasslands to welfare and amenity are likely to be very large.

Seagrass

The urban forest encompasses all of the natural parts of the urban environment, including green infrastructure such as trees, grasslands, and shrubs, and blue infrastructure, including rivers, canals and lakes. Recognising the unique environments which encompass our surroundings includes recognising that not all of our resources are directly in front of us, in fact, part of the urban forest is under the sea. While out of site often means out of mind, Torbay is, for the first time in any urban forest study, bringing marine forests and blue carbon into the spotlight.

As a coastal region, Torbay boasts 22 miles of coastline, and the coastal waters and bay which it encompasses. This means that the green infrastructure of Torbay includes unique resource- the beds of seagrass in the bay itself. Though it might not be the first thing that springs to mind when considering GI, seagrass provides habitat for a vast array of creatures, is an attraction for divers, and is well known to be an excellent carbon sink.[12]

There is approximately 52 ha of seagrass in the bay.[13]

It stores 6,300 tonnes of carbon in biomass and sediments; valued at £5.7 million.

Seagrasses are the only group of true marine flowering plants. Seagrass beds have a root system under the sediment (rhizomes) and long slender leaves above, which create a 'canopy'. It is also able to pollinate and set seed under the water.

Here in the UK, seagrass beds can be found in estuaries and sheltered bays, such as Torbay. They create complex habitats, providing homes for a rich variety of species and are a feature of the Torbay Marine Conservation Zone (MCZ). The protection from the MCZ aims to stop the degradation of these important habitats and the animals that live there, such as both species of UK seahorse, fan mussels and stalked jellyfish.

As well as creating a habitat full of a diverse array of species, seagrass beds provide a multitude of ecosystem services and support local livelihoods in coastal communities, such as Torbay. They are important for the juvenile stages of many commercial fish stocks. The dense root system stabilises sediments thus reducing coastal erosion and there is increasing

[12] Gerrard and Beaumont, 2014

[13] Field, 2019

evidence for its capacity to improve water quality.

As more people become aware of the marine life beneath the surface, many areas of Torbay are popular with divers, snorkelers and swimmers who enjoy this amazing habitat right on our doorstep.

The large capacity for seagrass beds to sequester carbon (CO_2) within their sediments has only been realised in recent years. 'Blue' carbon, sequestered in marine ecosystems is equivalent of around 2% of our emissions per year.[14] A healthy, dense bed with a well-developed rhizome mat can sequester carbon into the sediment which, if not disturbed, can store it for millennia. It can also end up conserved far beyond the boundaries of the beds themselves[15] due to sediment movements. Recent measurements found an average of 120 tonnes of C stored per hectare of seagrass in local seagrass beds.[16]

Despite all these benefits, due to coastal development and physical pressures, this fragile habitat faces many threats such as poor water quality from nutrient enrichment; physical damage from anchoring boats and swing moorings; increased recreational water use over seagrass beds; invasive species and disease. 39% of UK's seagrass has been lost just in the last 40 years and 96% in the last two centuries.[17]

Location	Total area (ha)	Carbon Storage (Tonnes)	Carbon Storage (£)
Breakwater	0.2	24	£22,000
Elberry cove	14.3	1,720	£1,560,000
Fishcombe	0.4	52	£47,200
Hope cove	2.0	242	£220,000
Livermead/ Torre Abbey	33.4	4,030	£3,660,000
Millstones/ Beacon cove	1.5	178	£161,000
Thatcher point	0.4	53	£48,100
TOTAL	**52.2**	**6,303**	**£5,718,300**

Table 5: Area and carbon storage of the seagrass beds in Torbay.

[14] Furness, 2021

[15] Duarte, 2017

[16] Green, 2018

[17] Green, 2021

Soil

After oceans, soil is the second largest natural carbon sink, surpassing forests and other vegetation in its capacity to capture carbon dioxide from air.[18] It is believed that the top 30 cm of the world's soil contains about twice as much carbon as the entire atmosphere.[19] In the UK, the largest terrestrial carbon stock lies in the soil.[20] Every soil possesses a limited carbon storage capacity which is a function of the vegetation type, climate, hydrology, topography and nutrient environment that the soil is exposed to.[21]

Soil is a vital resource which provides structural integrity, acts as a source of nutrients for plants, a regulator of hydrology and a habitat for a vast diversity of soil organisms, which in turn drive a range of biogeochemical processes.[22]

There have been studies carried out on soil carbon in the UK and carbon storage figures have been calculated for broad habitat types.

These values of carbon storage describe the top 15cm of soil under grasslands, and though it has been observed that soil carbon is stored below this depth, the values range too drastically to be applied as part of this study. It is also noted that urban grasslands may not have particularly deep soils as they may have been developed through the construction of the infrastructure, and are subject to environmental pressures such as pollution and compaction.

Under the assumption that the majority of soils across Torbay are neutral in pH, it is estimated that 184,000 tonnes of carbon are stored in the soils, with an estimated value of £166.9 million.

Soils can vary drastically from one location to another, often having a unique composition, therefore these estimates should be considered a rough and conservative guide to the potential of Torbay's soil carbon capacity.

Soil Type	Soil Carbon Storage	Source
Soil under Grassland		
Neutral	62 t/ha	Carey et al (2007)
	68.6 t/ha	Emmett et al (2010)
Acidic	82 t/ha	Carey et al (2007)
	90.6 t/ha	Emmett et al (2010)

Table 6. Carbon storage values for the top 15cm of soil for different soil types of soil under grasslands.

18 FAO, 2020

19 European Environment Agency, 2019

20 Bradley et al, 2005

21 Gupta and Rao, 1994

22 Lal,2004

Shade Provision and Urban Cooling

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

Table 9 (below) shows the effect Torbay's trees have on UV factors. The effects in tree shade indicates the reduction in UV for a person entirely in the shade. The UV effects overall are for people in the vicinity of the tree but not always sheltered, for example walking down the street.

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

Reduction in UV Index is the change in UV index as a result of trees and calculated as unshaded UV index minus the shaded or overall UV index.

Percent reduction is the reduction in UV index expressed as a percent change as calculated as the reduction in UV index divided by unshaded UV index.

	Protection Factor	Reduction in UV Index	Percent reduction (%)
UV Effects in Tree Shade	1.86	1.22	36.74
UV Effects Overall	1.38	0.62	26.78

Table 7: UV effects of trees in Torbay

Total Ecosystem Services Provided by Torbay's Green Infrastructure

This total represents only a handful of the benefits which these types of green infrastructure provide. In particular, the contribution which a healthy and diverse urban forest can make to biodiversity by supporting a healthy and complete ecosystem should not be overlooked. These systems are incredibly complex, and the pressures of Torbay's urban and coastal setting presents even more challenges for nature.

The value of all types of green infrastructure to people far exceeds the value of the services we are able to value too, supporting both physical and mental wellbeing, and creating an environment which people can enjoy both as visitors and residents of the area. The social benefits are valued separately from the ecosystem services [see chapters on CAVAT and ORVal].

Type	Carbon storage (Tonnes)	Carbon sequestration (Tonnes)	Pollution removal (Kg)	Stormwater Attenuation (m^3)	Total estimated value	Annual Estimated Value
Trees	172,000	4,910	67,300	195,000	£156 million	£6,460,000
Shrubs	Unknown	Unknown	38,700	Unknown	-	£1,140,000
Grasslands	Unknown	28	Unknown	Unknown	-	£256,000
Soil	184,000	Unknown	-	Unknown	£167 million	-
Seagrass	6,300	Unknown	-	-	£5.72 million	-

Table 8. Total ecosystem services valued for each type of green infrastructure.

Replacement Cost of Trees

The i-Tree Eco model provides a structural valuation which in the UK is termed the 'Replacement Cost'. It must be stressed that the way in which this value is calculated means that it does not constitute a benefit provided by the trees. The valuation is a depreciated replacement cost, based on the Council of Tree and Landscape Appraisers (CTLA) formulae.[23] Replacement Cost is intended to provide a useful management tool, as it is able to value what it might cost to replace any or all of the trees (taking account of species suitability, depreciation and other economic considerations) should they become damaged or diseased for instance. The replacement costs for the ten most valuable tree species are shown in Figure 13 (below).

The total replacement cost of all trees in the study area currently stands at £310 million, which averages around £680 per tree. *Acer pseudoplatanus* is currently the most valuable species of tree, on account of both its size and population, however *Quercus* is the most valuable genus, worth around £83 million.

A full list of trees with the associated replacement cost is given in Appendix II.

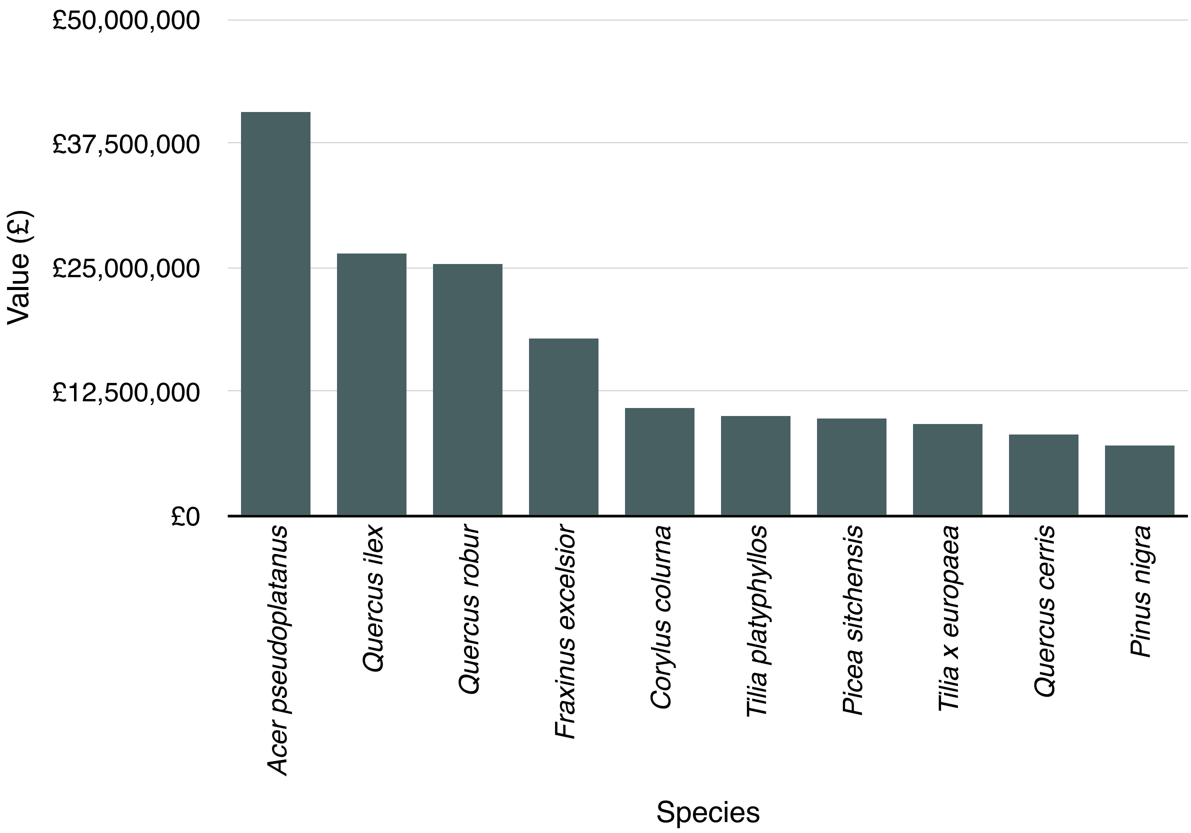


Figure 13: Replacement Cost of the 10 most valuable tree species in Torbay.

[23] Hollis (2007)

CAVAT - The Amenity Value of Torbay's Trees

Capital Asset Valuation for Amenity Trees (CAVAT) is a method which provides a value for the public amenity that trees provide, rather than the property approach taken in the CTLA method. Whilst CTLA provides a replacement cost for management purposes, the CAVAT value accounts for the greater amenity benefits of trees in areas of higher population density, This adds a further social dimension to Torbay's trees, placing a value on the trees visual accessibility and prominence in the landscape.

Torbay's trees are estimated to be worth over £4.1 billion in amenity value.

Although this is a seemingly large figure, it equates to around £8,950 per tree. *Acer pseudoplatanus* holds the highest value (Table 8), representing 13.8% of the value of all the trees, whilst *Quercus* ins the most valued genus, equating to 25.8% of the total value.

Species	Number of Trees	CAVAT Value
Acer pseudoplatanus	49,684	£564,975,500
Quercus robur	15,486	£353,184,400
Quercus ilex	25,810	£326,221,500
Picea sitchensis	645	£140,039,800
Tilia x europaea	1,936	£131,509,800
Corylus colurna	1,290	£128,387,400
Corylus avellana	34,843	£126,943,300
Fraxinus excelsior	64,524	£113,401,000
Cordyline australis	5,807	£112,979,800
Tilia platyphyllos	1,290	£108,423,200
All others	257,437	£1,998,302,000
Total	**458,752**	**£4,104,367,700**

Table 9. CAVAT values for the most valuable species in Torbay

Genus	Number of Trees	CAVAT Value
Quercus	52,265	£1,059,981,900
Acer	54,845	£623,943,900
Tilia	3,871	£291,929,900
Corylus	36,133	£255,330,700
Cupressus	32,262	£250,168,600
Fagus	12,905	£215,787,900
Fraxinus	83,236	£164,808,600
Picea	1,935	£140,837,600
Cordyline	7,097	£119,663,700
Cuprocyapris	29,036	£102,010,900
All others	145,167	£879,904,000
Total	**458,752**	**£4,104,367,700**

Table 10. CAVAT values for the most valuable genera in Torbay

Further details on the CAVAT methodology are included in Appendix V.

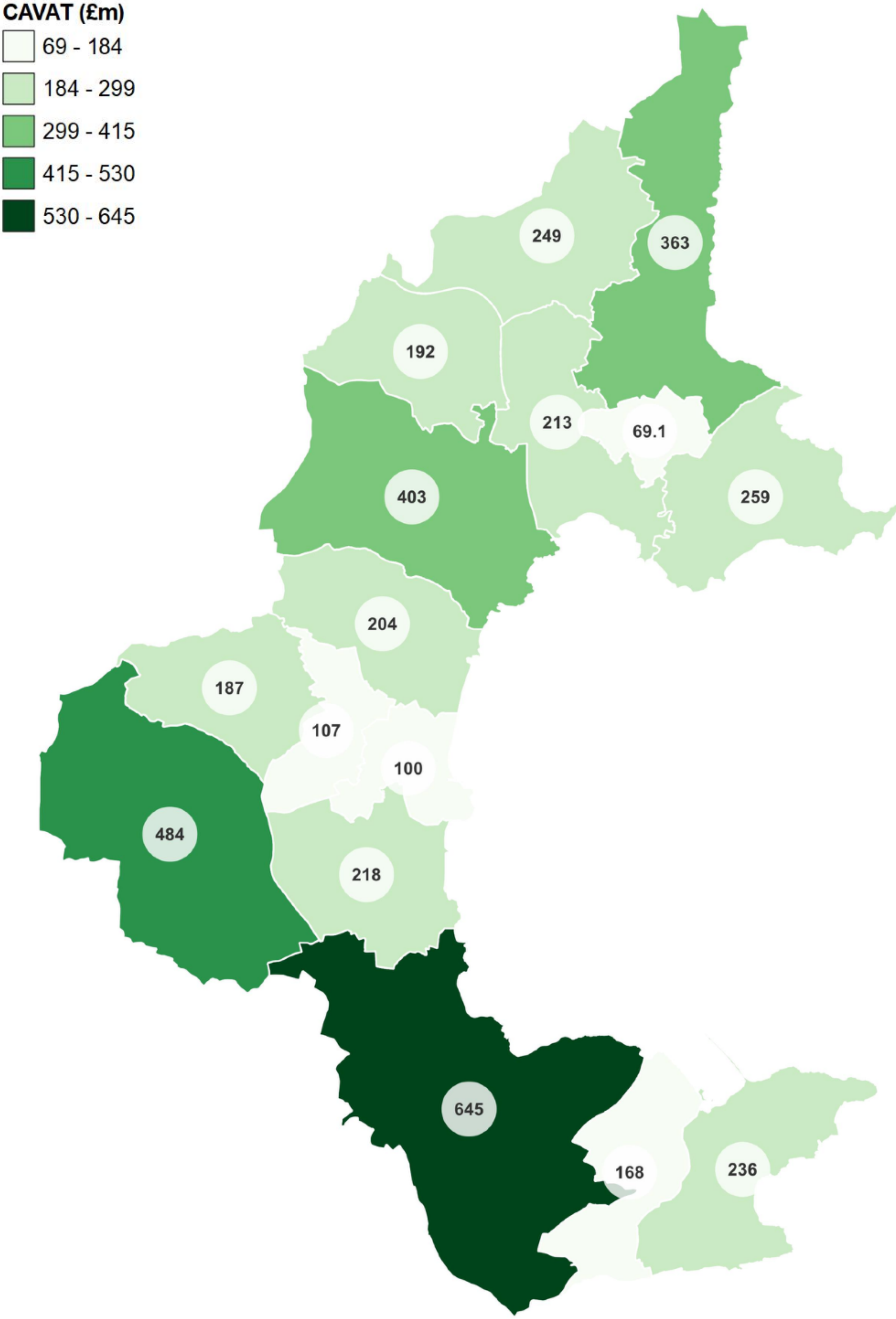


Figure 14: Map of CAVAT Value by Ward in Torbay

ORVal - The Recreational Value of Torbay's Green Spaces

ORVal is an online map-based application developed by the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter and DEFRA. The tool permits the interpretation and analysis of benefits derived from accessible green spaces across England and Wales.

The term 'welfare' incorporates a sense of well-being that an individual can gain through experience. The welfare value refers to the monetary equivalent of enjoyment by individuals as a result of having access to green space. This relates to the beneficial attributes of a site, e.g. the extent of woodland. It is estimated by calculating how much an individual's welfare would reduce if they no longer had access to the site.

Torbay's green spaces are visited an estimated 10,800,000 times each year by residents and tourists. This equates to 1,725 visits per hectare of Torbay's total area. The majority of these visits (60%) are not by car, implying that Torbay's inhabitants make good use of their surrounding parks and recreational area and that public transport links provide good connections. The welfare value of these visits totals £45 million per year.

The Torquay Central area sees the most visitors (1,290,000) at 12% of the total, and the greatest welfare value (£5,900,000) at 13% of the total each year. It also has by far the highest number of visits and welfare value per hectare, despite its comparatively smaller area.

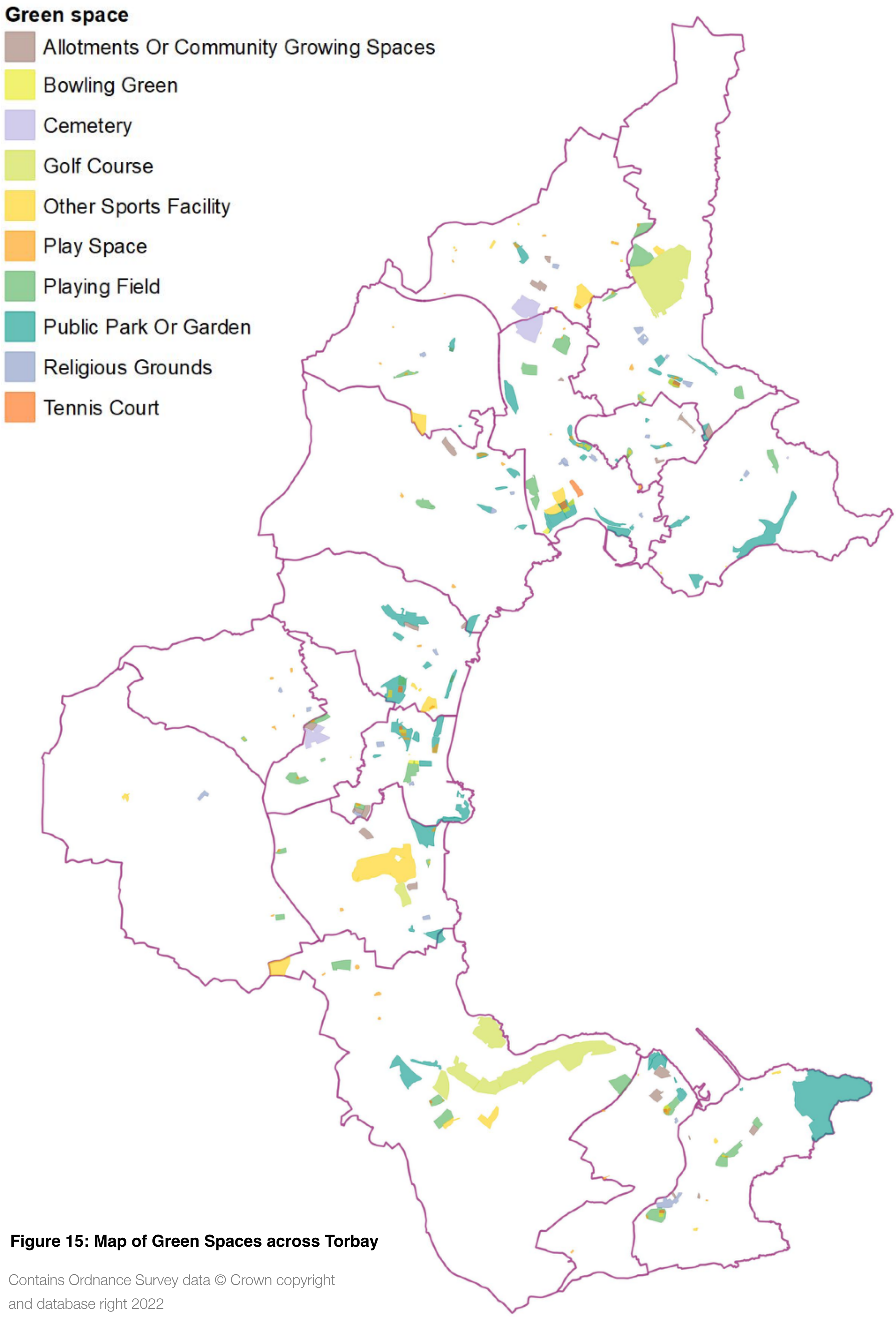


Figure 15: Map of Green Spaces across Torbay

Potential Pest and Disease Impacts

Pests and diseases are a serious threat to urban forests. It is likely that climate change will result in the introduction of pests and diseases not yet present in the UK. Warmer temperatures are likely to affect the geographical range, development rate and seasonal timing of life-cycle events of insects, and will have an impact on their host plants and predators.[24] The changing climate in the UK is predicted to increase growth or spore release of root pathogens, and to make trees more susceptible to infection.[25] Pests and diseases often occur most frequently within a particular tree family, genus or species. A tree population that is dominated by a few species is therefore more vulnerable to a significant impact from a specific disease than a more diverse population.

The pest posing a threat to the greatest percentage of Torbay's trees is Emerald Ash Borer. It attacks both ash and elm species, and is a major issue, though it is not currently present in the UK. Ash Dieback poses the largest current threat; it is already present in Torbay and could affect 18.1% of all trees. This disease is often fatal, and will likely be incredibly damaging to the urban forest. Table 11 (below) illustrates the percentage of species susceptible and the potential cost of an outbreak from the pathogens investigated.

Pest/Disease	Tree species affected	Prevalence in the UK	Population at risk (%)	Replacement cost (£)
Acute oak decline	Quercus robur, Q. petraea	Central and South East England, Welsh borders	11.4%	£82.9 mil
Asian longhorn beetle	Many broadleaf species	None (previous outbreaks contained)	18.1%	£53.3 mil
Bronze birch borer	Betula spp.	None	0.4%	£0.6 mil
Chalara dieback of ash	Fraxinus excelsior	Throughout England, Wales, Scotland, and Northern Ireland	18.1%	£27.5 mil
Dothistroma Needle Blight	Pinus spp.	Widespread	1.3%	£11.2 mil
Emerald ash borer	Fraxinus excelsior, Ulmus spp.	None	19.7%	£27.7 mil
Oak processionary moth	Quercus spp.	Established in London and South East England	11.4%	£82.9 mil
Phytophthora lateralis	Chamaecyparis lawsoniana	Isolated confirmed cases throughout UK. Most common in Scotland and Northern Ireland.	1.8%	£6.6 mil
Pine processionary moth	Pinus spp.	None	1.3%	£11.2 mil

Table 11: Risk assessment of selected tree pests and diseases for Torbay's urban forest.

[24] Wainhouse and Inward (2016)

[25] Frederickson-Matika and Riddell (2021)

Tree Condition

One of the most important factors 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 figure 20 below shows the health of the 10 most common trees in Torbay. Overall, tree health in Torbay is good, with 50% rated excellent condition and a further 26% rated good or fair. Less than 5% overall are beyond critical.

By far the least healthy of all trees encountered are the Ash (*Fraxinus excelsior*). Of these 64% were found to be in a 'poor' condition, and 32% in critical condition. This indicates the severity of the Ash Dieback disease in Torbay, and as *Fraxinus excelsior* is the most common tree species, and *Fraxinus* as a whole are the most common genus in Torbay, this is a serious concern.

Improving the diversity of species, and particularly the evenness of species across the population will increase the resilience of the urban forest as a whole.

It will be important to tackle Ash Dieback and prepare to replace the trees which will inevitably be lost. Selecting species which are suitable replacements for Ash is key to replacing the lost canopy cover and replacement species should have roughly the same potential for ecosystem service provision as those which are lost.

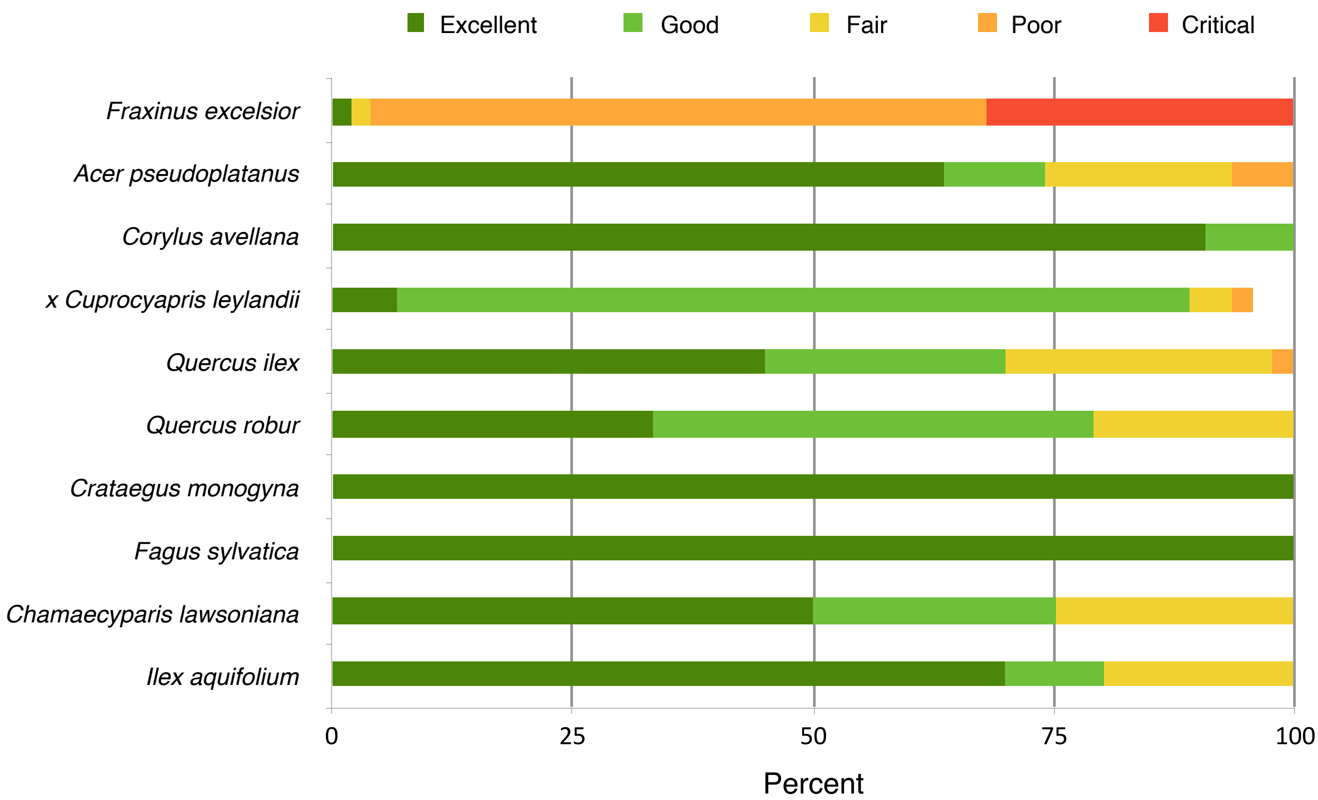


Figure 16: Condition of the 10 most common trees in Torbay.

In 2010, Torbay was the first town in the UK to undertake an i-Tree Eco Sample survey of its tree population.

This original study paved the way for the use of i-Tree in the UK, and has kick-started a drive for Councils to understand not only the structure of their urban forest resources, but also their value.

This is also the first time an I-Tree Eco sample study has been repeated in the UK!

How the Urban Forest Has Changed

Methods

Since i-Tree Eco was first used in Torbay, there have been a huge number of developments and updates to improve the programmes accuracy and capabilities. Therefore the values from the historic report are not directly comparable with the values of this study. By re-running the data from 2010 through the newest version of the programme, we can compare the structure and ecosystem services more comprehensively.

In order to remain consistent, the plots locations in this study were in the same as in 2010. The same weather and pollution data, and benefit values (£) have been used for both data sets. This means that though not entirely realistic, it is easier to compare the ecosystem services provided by trees.

It is noted that sampling methods have changes since the original study. Previously, all trees over 2.5cm in DBH were measured and included. Now, it is recommended that only trees over 7.5cm DBH and 3m tall are counted; anything smaller is considered a shrub. Therefore, all trees under 7.5cm DBH were removed from the 2010 data prior to the i-Tree analysis.

Updates to the software have meant that some things which were not measured in 2010 can now be quantified. In 2010, the pollutants analysed for pollution removal included PM_{10}, but did not include $PM_{2.5}$. For the comparison to be meaningful, the data for both years includes $PM_{2.5}$ and excludes PM_{10}. Stormwater attenuation was also not previously included, however it is in the new comparison.

Headline Figures

Structure and Composition Compared

	2010	2022
Number of Trees (estimated)	692,000	458,800
Tree Canopy Cover	11.8%	18.2%
Tree Density (trees/hectare)	109	71
Most Common Tree Species	*Cuprocyapris leylandii, Fraxinus excelcior, Acer pseudoplatanus*	*Fraxinus excelcior, Acer pseudoplatanus, Corylus Avellana*
Replacement Cost (CTLA)	£371 million	£310 million

Ecosystem Services Compared

	2010		2022		Difference
	Amount	Value	Amount	Value	
Carbon Storage	153,600 tonnes	£139,652,000	172,000 tonnes	£156,396,000	18,400 tonnes ▲
Annual Carbon Sequestration	5,680 tonnes	£5,173,000	4,910 tonnes	£4,465,000	-770 tonnes ▼
Annual Pollution Removal	57 tonnes	£1,304,000	67 tonnes	£1,211,700	10 tonnes ▲
Annual Avoided Runoff	157,900 m^3	£520,000	195,300 m^3	£643,400	37,400 m^3 ▲

Table 12. Comparisons of structure and ecosystem services delivered by Torbay trees in 2010 and 2022

The number of trees observed across Torbay has dropped by over 230,000 trees. Though this seems dramatic, tree canopy cover has increased by 6.4%. This indicates that the trees that have been lost were mostly small in stature and not contributing significantly to canopy cover or ecosystem service provision. This is not an unusual occurrence in urban environments, as urban trees are subject to additional pressures which affect mortality, particularly in young trees, such as pollution and compaction.

Carbon sequestration has decreased, however this supports the idea that the trees which have been removed were young; young trees grow quickly and sequester large amounts of carbon in their first 10-20 years of life.

Though pollution removal has increased since 2010, the value of this has decreased. This is because the remaining species remove less $PM_{2.5}$ each year than in 2010. A key aspect of this is the loss of many Leyland cypress, reducing the contributions of this species by almost 50%. This once dominant species has gone from representing 16% of the population, to 6%, leaving *Fraxinus excelsior* to dominate despite the pressure of disease.

The question now is, are there enough young trees to support the ageing population?

In the last decade, tree numbers have dropped, but canopy cover and annual benefits have increased

Conclusions

The Trees of Torbay's urban forest are a valuable resource, providing a wide range of benefits to the local people and those who visit the area.

Managing a forest purely for ecosystem services such as carbon sequestration, pollution removal or stormwater attenuation can result in a lack of diversity and as big, old trees are favoured, often the small trees are overlooked. In a borough such as Torbay, diversity is a vital aspect which greatly impacts the overall aesthetic of the green infrastructure. Torbay performs fairly well in terms of diversity, with 62 species of tree, and an additional 93 species of shrub identified, however continuing to promote an evenly distributed population will increase the sustainability of the urban forest.

Torbay has lost a large number of trees, however its canopy cover has increased significantly. This is likely due to the thinning of understory, high mortality of young trees in urban areas, and a lack of tree planting. The management of the older, larger trees has countered this so far, however without young trees, the population cannot support itself. As the old trees expire, younger trees must be ready to take their place in order to avoid a serious population decline. Increasing tree planting and boosting the younger tree population would also increase the annual carbon sequestration of the urban forest.

The cost of Ash dieback in Torbay in coming years could be enormous; dying trees can pose risks to the public and to transport networks, so removing them will be a big task. Not only will it cost to remove and replace these trees, but the loss of these trees will greatly reduce the ecosystem service benefits provided annually, the amenity value of the urban forest and the unquantifiable benefits such as shade provision and urban cooling, biodiversity, and resilience to climate change.

Trees and green infrastructure also provide other, immeasurable benefits, such as improving health and wellbeing, supporting local wildlife and reducing the temperature of urban spaces. The measures of amenity and recreation value are often considered to be underestimates of their true value to people, however, as there are no measures of the emotional response of people to trees and green spaces.

Trees can save lives by cleaning air of pollutants and by offering shade during heat waves

The urban forest offers more than just financial pay-back; it can save lives. Airborne pollutants such as particulate matter can cause and exacerbate respiratory illnesses, particularly in heavily urbanises areas and along transport links. Trees can trap and remove these particles from the air, thereby reducing the concentration of particulate matter and reduce the negative effects of them. Also, trees provide shade and can greatly reduce the overall temperature of urban centres. Heat stroke and other heat related illnesses are believed to have resulted in the deaths of 2,500 people in the UK in 2020.[26] This is a particular concern for Torbay as a summer holiday destination, and continuing to improve and develop the tree canopy cover will help to reduce the risk to residents and visitors in the face of climate change.

[26] Public Health England (2020)

Recommendations

The results and data from previous i-Tree Eco studies have been used in a variety of ways to better manage trees and inform decision making. With better information we can make better decisions regarding trees and this is one of the key benefits of undertaking a project such as this.

For example, in relation to the benefits assessed by i-Tree, the trees that offer the greatest benefits are those that are larger and therefore have a greater canopy cover. This is because leaf area is the driving force of tree benefits, increasing their capacity to sequester carbon and filter pollution etc. In order for this to be realised trees need to be able to achieve larger canopy. This can be achieved through appropriate thinning and management, species selection and planting location.

Additional to the quantifiable benefits, biodiversity value is also increased, maintenance costs are reduced, and the tree stock is of generally better quality, being less stressed. This in turn reduces the susceptibility of trees to pests and diseases. Woodland compartments that are not managed are much less likely to achieve these objectives.

In particular, the authors would like to draw attention to the following recommendations:

- A wide diversity of tree species should be planted (with due consideration to local site factors) to replace the future loss of Ash, whilst also reducing the over-reliance on key species (such as Sycamore) in the future, reducing the likelihood of severe impact from any given pest or disease outbreak.
- Ensure that new planting is done for the right reasons; planting trees purely for ecosystem services can result in reduced diversity, and should therefore be avoided. Include a mixture of 'ES trees' and 'amenity trees' in the right locations.
- Increased tree planting and post-planting management and care of young trees to support the existing, ageing population.
- Continuing to protect existing mature and maturing trees where possible to increase the provision of benefits.
- Undertake a full policy review to maximise the impacts from this survey on securing future funding.
- An Urban Forest Master Plan would be a useful step in developing a comprehensive plan for understanding and developing the urban forest of Torbay.

Appendix I. Relative Tree Effects

The trees 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 municipal carbon emissions, average passenger automobile emissions, and average household 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 (C) emitted in Torbay in 100 days
- Annual emissions from 134,000 automobiles
- Annual C emissions from 55,000 single-family houses

Carbon monoxide removal is equivalent to:

- Annual emissions from 6 automobiles
- Annual emissions from 16 single family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 688 automobiles
- Annual nitrogen dioxide emissions from 310 single-family houses

Sulphur dioxide removal is equivalent to:

- Annual sulphur dioxide emissions from 25,900 automobiles
- Annual sulphur dioxide emissions from 140 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Torbay in 2.9 days
- Annual C emissions from 3,800 automobiles
- Annual C emissions from 1,600 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 II. Species Dominance Values and Leaf Area

Species	Percent Leaf Area	Percent Population	Dominance Value
Fraxinus excelsior	11.9%	14.1%	26.00
Acer pseudoplatanus	12.9%	10.8%	23.70
Quercus ilex	10.5%	5.6%	16.10
Corylus avellana	5.8%	7.6%	13.40
Cupressus	2.8%	6.9%	9.70
Quercus	7.1%	1.8%	9.00
Quercus robur	5.4%	3.4%	8.80
Fraxinus	3.4%	3.9%	7.40
x Cuprocyapris leylandii	0.7%	6.3%	7.10
Crataegus monogyna	2.2%	2.8%	5.00
Picea sitchensis	4.8%	0.1%	4.90
Fagus sylvatica	2.5%	2.4%	4.90
Platanus	0.6%	3.9%	4.50
Quercus cerris	3.9%	0.4%	4.30
Tilia x europaea	3.3%	0.4%	3.80
Chamaecyparis lawsoniana	1.6%	1.7%	3.30
Fagus	2.7%	0.4%	3.20
Tilia platyphyllos	2.6%	0.3%	2.90
Malus	0.3%	2.4%	2.70
Acer campestre	1.3%	0.8%	2.10
Prunus avium	0.9%	0.8%	1.80
Laurus nobilis	0.5%	1.1%	1.60
Ilex aquifolium	0.2%	1.4%	1.60
Sabal palmetto	0.2%	1.4%	1.60
Castanea sativa	0.8%	0.6%	1.40
Ricinus	<0.1%	1.4%	1.40
Quercus laevis	1.1%	0.1%	1.30
Sambucus nigra	0.9%	0.4%	1.30
Cordyline australis	<0.1%	1.3%	1.30
Larix	0.7%	0.6%	1.20
Alnus glutinosa	0.8%	0.3%	1.10

Species	Percent Leaf Area	Percent Population	Dominance Value
Pinus	0.4%	0.6%	1.00
Crataegus	0.3%	0.6%	0.90
Ulmus procera	0.1%	0.8%	0.90
Tilia cordata	0.6%	0.1%	0.80
Cupressus macrocarpa	0.6%	0.1%	0.70
Pittosporum	0.3%	0.4%	0.70
Salix	0.3%	0.4%	0.70
Taxus baccata	0.3%	0.4%	0.70
Prunus laurocerasus	0.1%	0.6%	0.70
Pinus nigra ssp. salzmannii	0.3%	0.3%	0.60
Betula	0.2%	0.4%	0.60
Ulmus glabra	0.1%	0.6%	0.60
Populus nigra	0.4%	0.1%	0.50
Alnus serrulata	0.3%	0.3%	0.50
Carpinus betulus	0.3%	0.1%	0.50
Araucaria araucana	0.2%	0.3%	0.50
Pyrus communis	0.1%	0.4%	0.50
Sorbus aucuparia	0.1%	0.4%	0.50
Robinia pseudoacacia	0.3%	0.1%	0.40
Pinus nigra	0.1%	0.3%	0.40
Aesculus x carnea	0.2%	0.1%	0.30
Cedrus	0.2%	0.1%	0.30
Liquidambar styraciflua	0.2%	0.1%	0.30
Acer platanoides	0.1%	0.1%	0.30
Salix x sepulcralis	0.1%	0.1%	0.30
Arecastrum	<0.1%	0.3%	0.30
Cordyline	<0.1%	0.3%	0.30
Cornus	<0.1%	0.3%	0.30
Corylus colurna	<0.1%	0.3%	0.30
Magnolia	<0.1%	0.3%	0.30
Picea	<0.1%	0.3%	0.30
Prunus	<0.1%	0.3%	0.30

Species	Percent Leaf Area	Percent Population	Dominance Value
Prunus padus	<0.1%	0.3%	0.30
Sambucus canadensis	<0.1%	0.3%	0.30
Acer	0.1%	0.1%	0.20
Aesculus hippocastanum	0.1%	0.1%	0.20
Cotinus coggygria	0.1%	0.1%	0.20
Fraxinus angustifolia	0.1%	0.1%	0.20
Magnolia grandiflora	0.1%	0.1%	0.20
Nothofagus	0.1%	0.1%	0.20
Phoenix canariensis	0.1%	0.1%	0.20
Pinus mugo	0.1%	0.1%	0.20
Salix alba	0.1%	0.1%	0.20
Cornus florida	<0.1%	0.1%	0.20
Elaeagnus pungens	<0.1%	0.1%	0.20
Griselinia	<0.1%	0.1%	0.20
Ilex	<0.1%	0.1%	0.20
Juniperus	<0.1%	0.1%	0.20
Prunus cerasifera	<0.1%	0.1%	0.20
Prunus domestica	<0.1%	0.1%	0.20
Prunus occidentalis	<0.1%	0.1%	0.20
Rhus	<0.1%	0.1%	0.20
Salix caprea	<0.1%	0.1%	0.20
Ulmus	<0.1%	0.1%	0.20
Chamaecyparis	<0.1%	0.1%	0.10
Mespilus germanica	<0.1%	0.1%	0.10
Metasequoia glyptostroboides	<0.1%	0.1%	0.10
Persea	<0.1%	0.1%	0.10
Syringa	<0.1%	0.1%	0.10
Trachycarpus fortunei	<0.1%	0.1%	0.10

Appendix III. Tree values by species

Species	Number of Trees	Carbon Storage (Tonnes)	Gross Carbon Sequestration (Tonnes)	Avoided Runoff (m³)	Replacement Cost
Fraxinus excelsior	64,524	11,343	405	23,250	£17,749,850
Acer pseudoplatanus	49,684	17,732	604	25,211	£40,651,977
Corylus avellana	34,843	1,973	102	11,423	£5,247,448
Cupressus	31,617	13,579	642	5,413	£10,486,169
x Cuprocyapris leylandii	29,036	5,630	428	1,435	£3,712,214
Quercus ilex	25,810	14,477	413	20,426	£26,339,341
Fraxinus	18,067	8,455	164	6,696	£9,400,191
Platanus	18,067	763	53	1,172	£2,038,927
Quercus robur	15,486	8,769	251	10,642	£25,221,609
Crataegus monogyna	12,905	2,978	56	4,237	£6,005,387
Fagus sylvatica	10,969	2,376	84	4,972	£4,335,687
Malus	10,969	946	54	623	£2,053,831
Quercus	8,388	8,308	176	13,934	£16,860,937
Chamaecyparis lawsoniana	7,743	2,456	63	3,160	£6,530,050
Ilex aquifolium	6,452	446	21	362	£995,739
Ricinus	6,452	702	68	51	£589,709
Sabal palmetto	6,452	248	5	325	£661,055
Cordyline australis	5,807	4,910	62	65	£3,579,654
Laurus nobilis	5,162	2,033	80	941	£2,058,518
Acer campestre	3,871	1,402	18	2,511	£3,239,377
Prunus avium	3,871	1,097	30	1,817	£2,511,654
Ulmus procera	3,871	60	6	157	£38,115
Castanea sativa	2,581	1,392	34	1,628	£5,466,768
Crataegus	2,581	327	16	654	£798,520
Larix	2,581	336	24	1,326	£132,275
Pinus	2,581	2,227	62	849	£3,656,114
Prunus laurocerasus	2,581	116	18	210	£200,312
Ulmus glabra	2,581	176	13	162	£86,616
Betula	1,936	344	20	314	£571,746

Species	Number of Trees	Carbon Storage (Tonnes)	Gross Carbon Sequestration (Tonnes)	Avoided Runoff (m³)	Replacement Cost
Fagus	1,936	9,540	158	5,362	£11,760,708
Pittosporum	1,936	1,680	24	568	£2,358,450
Pyrus communis	1,936	74	10	127	£164,528
Quercus cerris	1,936	3,256	17	7,631	£8,201,406
Salix	1,936	1,349	53	545	£1,762,361
Sambucus nigra	1,936	1,235	7	1,680	£2,388,937
Sorbus aucuparia	1,936	94	11	159	£168,824
Taxus baccata	1,936	187	8	538	£410,525
Tilia x europaea	1,936	6,480	125	6,524	£9,165,614
Alnus glutinosa	1,290	129	5	1,529	£1,150,784
Alnus serrulata	1,290	24	3	493	£92,915
Araucaria araucana	1,290	702	19	452	£3,081,022
Arecastrum	1,290	29	1	7	£895,872
Cordyline	1,290	114	7	10	£738,270
Cornus	1,290	48	6	72	£61,324
Corylus colurna	1,290	8,931	87	32	£10,827,085
Magnolia	1,290	97	7	90	£147,394
Picea	1,290	30	5	12	£74,848
Pinus nigra	1,290	31	3	134	£160,537
Pinus nigra ssp. salzmannii	1,290	3,020	42	653	£6,949,861
Prunus	1,290	333	11	87	£437,976
Prunus padus	1,290	27	4	59	£89,044
Sambucus canadensis	1,290	10	1	74	£84,204
Tilia platyphyllos	1,290	3,662	49	5,113	£9,980,182
Acer	645	170	10	112	£201,666
Acer platanoides	645	374	11	266	£704,419
Aesculus hippocastanum	645	160	5	179	£182,364
Aesculus x carnea	645	137	8	312	£149,613
Carpinus betulus	645	92	6	640	£224,690

Species	Number of Trees	Carbon Storage (Tonnes)	Gross Carbon Sequestration (Tonnes)	Avoided Runoff (m³)	Replacement Cost
Cedrus	645	1,152	26	356	£2,040,322
Chamaecyparis	645	23	3	12	£31,940
Cornus florida	645	29	2	71	£29,837
Cotinus coggygria	645	45	3	129	£55,338
Cupressus macrocarpa	645	1,074	0	1,116	£2,113,744
Elaeagnus pungens	645	52	7	56	£41,771
Fraxinus angustifolia	645	121	5	190	£324,556
Griselinia	645	189	10	88	£201,721
Ilex	645	27	3	25	£48,393
Juniperus	645	391	13	69	£409,263
Liquidambar styraciflua	645	32	3	345	£74,260
Magnolia grandiflora	645	64	4	100	£136,842
Mespilus germanica	645	110	8	18	£74,260
Metasequoia glyptostroboides	645	4	1	12	£37,775
Nothofagus	645	275	13	114	£236,605
Persea	645	24	3	17	£39,631
Phoenix canariensis	645	58	1	147	£900,128
Picea sitchensis	645	4,074	5	9,334	£9,875,816
Pinus mugo	645	198	6	99	£478,303
Populus nigra	645	1,165	25	759	£3,243,583
Prunus cerasifera	645	94	5	72	£123,582
Prunus domestica	645	25	3	21	£31,940
Prunus occidentalis	645	154	9	81	£78,320
Quercus laevis	645	2,117	1	2,204	£6,292,291
Rhus	645	34	3	48	£64,099
Robinia pseudoacacia	645	86	5	603	£297,806
Salix alba	645	308	12	194	£1,388,468
Salix caprea	645	279	4	33	£911,360
Salix x sepulcralis	645	211	11	225	£657,219

Species	Number of Trees	Carbon Storage (Tonnes)	Gross Carbon Sequestration (Tonnes)	Avoided Runoff (m^3)	Replacement Cost
Syringa	645	19	3	16	£48,393
Tilia cordata	645	1,723	27	1,257	£5,547,921
Trachycarpus fortunei	645	26	1	7	£180,070
Ulmus	645	176	10	97	£111,802
Total	458,768	171,974	4,910	195,340	£309,962,568

Appendix IV. Notes on Methodology

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

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

In the field 0.04 hectare plots were randomly distributed. All field data were collected during the leaf-on season to properly assess tree canopies. Within each plot, data collection includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback.

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.[27] 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.

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost

27 Nowak 1994

resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of trees account for decomposition[28].

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

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulphur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models[29]. 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[30] [31] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere.[32]

Annual avoided surface run-off is calculated based on rainfall interception by vegetation, specifically the difference between annual run-off with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface run-off, only the precipitation intercepted by leaves is accounted for in this analysis. The value of avoided run-off is based on estimated or user-defined local values. As the local values include the cost of treating the water as part of a combined sewage system the lower, national average externality value is reported.

Replacement Costs were based on valuation procedures of the Council of Tree and Landscape Appraisers which uses tree species, diameter, condition and location information[33] [34].

An amended CAVAT quick method was chosen to assess the trees in this study, in conjunction with the CAVAT steering group (as done with previous i-Tree Eco studies in the UK).

In calculating CAVAT the following data sets are used:

• the current Unit Value, representing the fiscal value of the tree, by cross-sectional area,

• Diameter at Breast Height (DBH),

• Community Tree Index (CTI) rating, reflecting local population density,

• an assessment of accessibility,

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[28] Nowak et al 2007

29 Baldocchi 1987, 1988

30 Bidwell and Fraser 1972

31 Lovett 1994

32 Zinke 1967

33 Hollis (2007)

34 Rogers et al (2012)

• an assessment of overall functionality, (that is the health and completeness of the crown of the tree);

• an assessment of Life Expectancy.

The current Unit Value is determined by the CAVAT steering group and is currently set at £16.26.

DBH is taken directly from the field measurements.

The CTI rating is determined from the LTOA approved list and is calculated on a borough by borough basis.

For a full review of the model see UFORE (2010) and Nowak and Crane (2000).

For UK implementation see Rogers et al (2014).

For full review of CAVAT see Doick et al (2018).

Full citation details are located in the bibliography section.

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