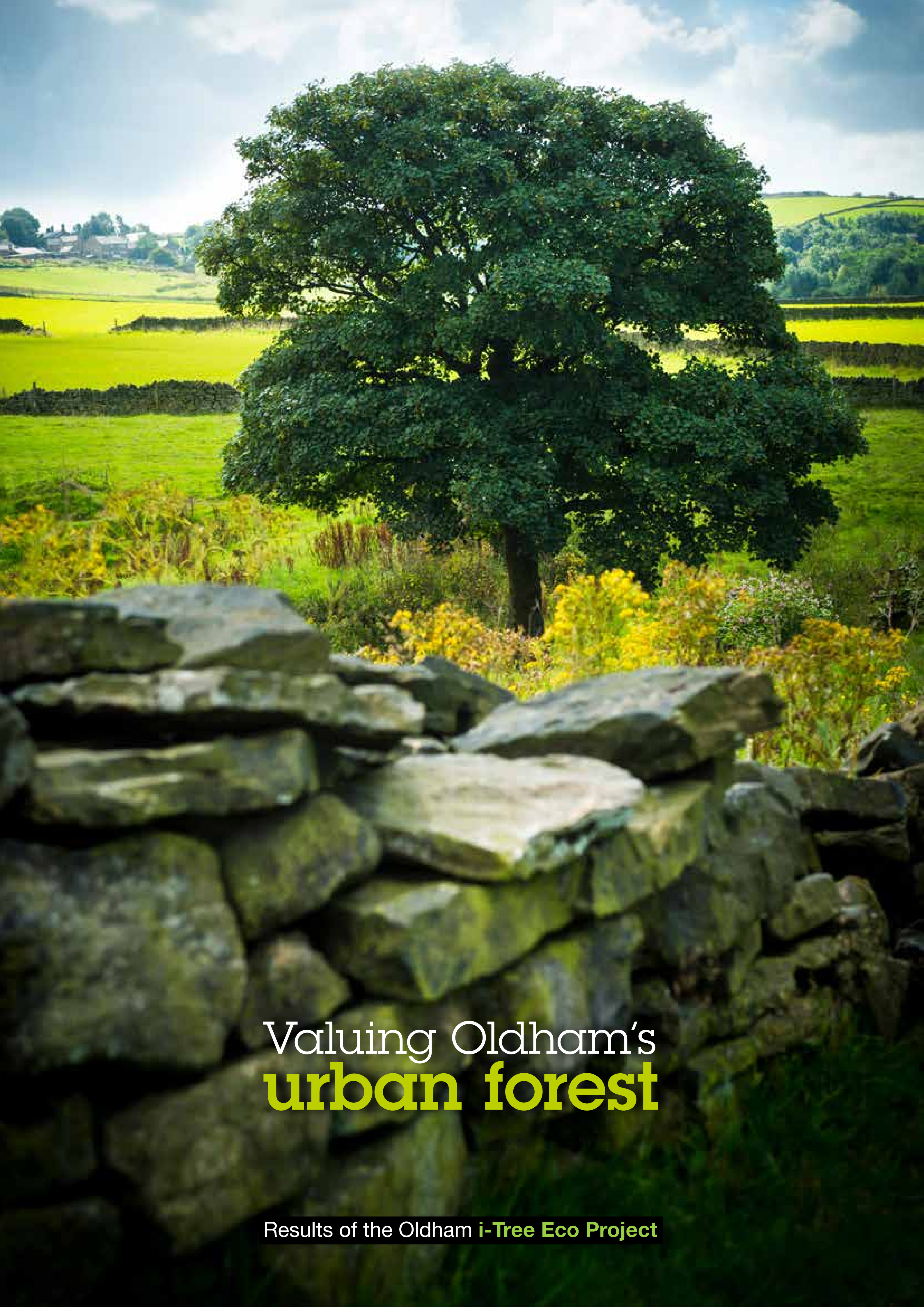
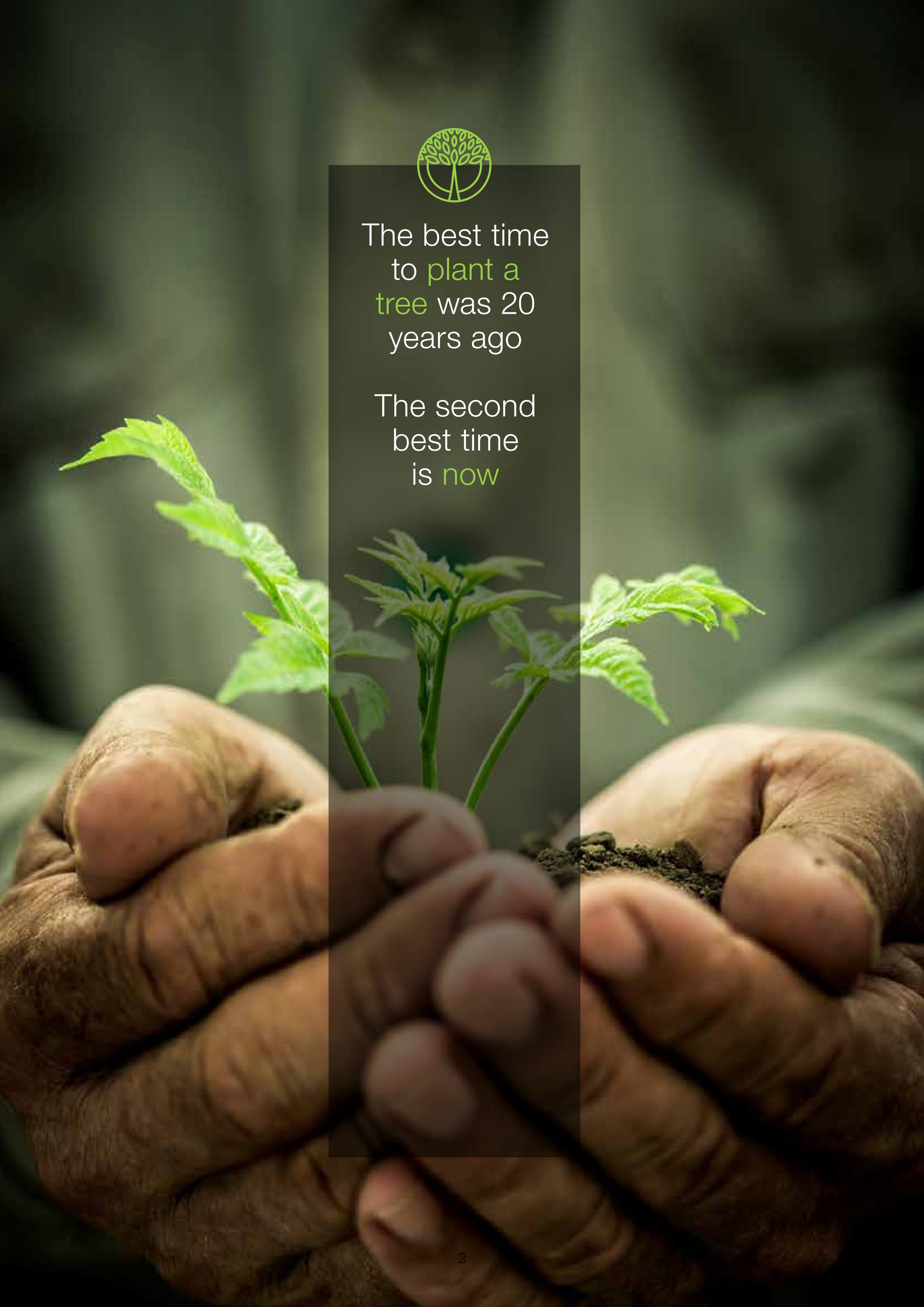


Valuing Oldham's urban forest

Results of the Oldham **i-Tree Eco Project**



The best time to plant a tree was 20 years ago

The second best time is now

Contents

Photograph: Strinesdale Country Park

Foreword

Councillor Sean Fielding

Leader
Oldham Council

Oldham's i-Trees Eco project is an exciting way to quantify the ecosystem benefits provided by trees and place a financial value to those benefits through sound methodology, so that they can be fully recognised for being the assets they truly are.

It's great to see Oldham leading the way in Greater Manchester with this forward thinking and important study.

The results are fascinating and will be put to great use in the strategic planning of Oldham's urban forest.
I hope this report helps highlight how important trees are to the borough and the positive environmental impact they have.

I was particularly pleased with the collaborative and co-operative approach to the project and must take this opportunity to thank and congratulate all those involved.

Dr Carolyn Wilkins OBE

Chief Executive, Oldham Council. Accountable Officer NHS Oldham CCG

Oldham Council is constantly looking to improve and enhance living standards for our residents.

Understanding Oldham's urban forest is a significant step towards a more proactive approach to the management of this important resource.

From this detailed understanding we can plan to improve and maintain our urban forest, which in turn will help make Oldham a cleaner, greener and healthier place to live, work and visit.

This study demonstrates the massive benefits that trees provide and how they are one of our most important assets.
I look forward to seeing the proposals and outcomes generated from gathering such detailed knowledge and data.

Well done to all who were involved, especially the many volunteers who contributed so generously with their time.

Councillor Ateeque Ur-Rehman

Cabinet Member for Neighbourhoods Services

This is another excellent example of the good work going on across Oldham.
I think we all know that trees are a good thing within the urban environment, but having some of their many benefits quantified in this way is extremely interesting and important.

With Ash Dieback Disease now widespread in the UK this report has come along just in time so that we can plan a more resilient and diverse tree population for Oldham.

I applaud all those involved in this ground-breaking research and the co-operative approach with which it was undertaken.

Executive summary

All the trees in **Oldham's** streets, gardens, woodlands and open spaces can be considered as its '**urban forest**'

This urban forest provides a multitude of benefits both environmental and aesthetical. The scale and effectiveness of the environmental benefits (or ecosystem services) such as air quality improvement, carbon sequestration or temperature reduction, are directly influenced by the way we manage the resource, decisions and actions that affect its structure and composition over time.

We know that maintaining and improving Oldham's urban forest has considerable public support, but also that much of the urban forest has grown and matured in conditions very different from the cityscape of today. Consequently, we need to have a good understanding of the structure and value of Oldham's urban forest to ensure that we are implementing appropriate management, maintenance and planting regimes that will result in maintaining and increasing the canopy cover over time.

A first and necessary step is to better understand the current structure, composition and distribution of Oldham's urban forest, in order to obtain a baseline from which to set goals and to monitor progress. Furthermore, by measuring the structure of the urban forest (the physical attributes such tree density, tree health, leaf area and biomass), the benefits of the urban forest can also be determined, and the value of these benefits calculated and expressed in monetary terms.

Headline figures

				Total
Number of Trees	FCHO Urban	13,400		466,800
	Rural	253,300		
	Urban	200,100		
Tree Species Recorded	FCHO Urban	20		59
	Rural	12		
	Urban	50		
Replacement Cost	FCHO Urban	£10,560,000.00		£231,000,000.00
	Rural	£107,730,000.00		
	Urban	£112,710,000.00		
Most Common Species	FCHO Urban	Cypress, Sycamore, Maple		
	Rural	Alder, Ash, Larch		
	Urban	Alder, Ash, Spruce		
Tree Cover / Canopy Cover				11.8% / 16.9%
Pollution Removal (per annum)	FCHO Urban	2.04 Tonnes	£32,252.00	£1,026,650.00
	Rural	39.50 Tonnes	£624,974.00	
	Urban	23.30 Tonnes	£369,424.00	
Carbon Storage (whole value)	FCHO Urban	2,712 Tonnes	£175,000.00	£4,250,000.00
	Rural	32,098 Tonnes	£2,050,000.00	
	Urban	31,697 Tonnes	£2,025,000.00	
Carbon Sequestration (per annum)	FCHO Urban	153.00 Tonnes/Yr	£9,770.00	£202,250.00
	Rural	1,502.00Tonnes/Yr	£95,880.00	
	Urban	1,513.00 Tonnes/Yr	£96,600.00	
Avoided Runoff (trees)	FCHO Urban	123,382m³	£187,090.00	£307,300.00
	Rural	72,932m³	£110,550.00	
	Urban	6,367m	£9,660.00	
Amenity Value (CAVAT)				£1,789,754,700.00
Total Annual Benefits				£1,536,200.00

Introduction

Trees and woodlands provide a valuable habitat for much of the UK's **urban wildlife**

Urban trees provide a range of beneficial services which are of particular importance in the urban environment. Despite widespread public appreciation of the amenity value of trees the full range of benefits provided by the urban forest are often unnoticed, unappreciated and undervalued. Recognising and evaluating these benefits can help us to make the right decisions about how best to manage our urban trees.

These benefits or 'ecosystem services' include the reduction of the urban heat island effect through shading and evaporative cooling[1]; the improvement of local air and water quality by absorbing and filtering pollutants[2]; and additional health benefits such as reducing stress levels and improving recovery time from illness[3].

Trees also store carbon, absorbing it into their tissues, helping to offset carbon emissions produced by other urban activities[4]. They can also help alleviate flash flooding, a problem that costs cities millions of pounds each year[5]. Commercial and private property value can be enhanced by being located in tree-lined streets or neighbourhoods[6]. An increase in tree cover and greenery has also been shown to reduce crime[7] and encourage greater consumer spending[8]. Trees and woodlands also provide a valuable habitat for much of the UK's urban wildlife, including bats[9] and bees[10].

Many of the ecosystem services provided by urban trees are quantifiable using models such as i-Tree Eco. i-Tree Eco is currently the most complete method available to value a whole suite of urban forest ecosystem services[11], including pollutant interception and carbon uptake. i-Tree Eco has been used successfully in more than 100 countries, including several cities in the UK. It is also capable of providing detailed results on the structure and functions of the trees that make up the urban forest.

[1] Akbari, Pomerantz & Taha 2001
[2] Bolund & Hunhammar 1999
[3] Ulrich 1979
[4] Nowak, Crane, Stevens, et al. 2008
[5] Bolund & Hunhammar 1999
[6] Forestry Commission 2010
[7] Troy 2012
[8] Wolf 2007
[9] Entwistle, Harris, Hutson, et al. 2001
[10] RHS 2012
[11] Sarajevs 2011

Methodology

Given the importance of the urban tree resource, knowledge of the contribution that trees make to society needs to be available for the strategic planning and management of this infrastructure. This requires that key information be gathered so that the resource can be protected and enhanced, and its crucial functionality maintained.

i-Tree Eco was designed to use standardised field data from randomly generated plots across a whole study area. i-Tree Eco calculates the species and age class structure, biomass and leaf area index (LAI) of the urban forest. This data is then combined with local climate and air pollution data to produce estimates of a number of ecosystem services and to assess their current and future value.

For the Oldham i-Tree Eco assessment, a total of two hundred and nineteen plots were selected from a randomised grid covering both urban and rural Oldham.

i-Tree Eco uses a standardised field collection method outlined in the i-Tree Eco Manual (v 6.0 for this study). This method was applied to each plot. Each plot covered 0.04ha. Field data was collected by volunteers, Oldham Council staff and First Choice Homes staff who were assisted and trained by Treeconomics.

The information recorded from each plot was as follows:

- **The type of land use encountered. For example park, residential, etc.**
- **The percentage distribution of cover present in the plot. For example grass, tarmac, etc.**
- **The percentage of the plot available for future tree planting.**

The following specific information about trees with a stem diameter of 7cm dbh (diameter at breast height). Trees below this size were not considered as part of the survey following standard forestry practice.

- **The number of trees and species of trees present.**
- **The size of the trees, including height, canopy spread and diameter of trunk.**
- **The health of the trees including the fullness of the canopy and percentage of canopy missing.**
- **The amount of light exposure the canopy receives.**

Information about shrubs less than 7cm in dbh were also gathered and the size and dimensions of the shrubs were recorded.

From this data a three dimensional numeric model of the total biomass, its distribution and condition is constructed within the i-Tree model, enabling the calculation of the total ecosystem services delivered to be calculated.

For this study the project area of Oldham was further sub divided (stratified) into the rural, urban and First Choice Homes Estate areas.

This data was submitted to the US Forest Service for use in the i-Tree Eco model and a number of outputs are the calculated (Table 2 below).

Table 2: Outputs calculated based on field collected data

Urban forest structure and composition	• Land use and ground cover • Importance Value • Leaf area • Species and size class distribution
Ecosystem services	• Air pollution removal by urban trees for CO, NO_2, SO_2, O_3 and PM2.5. • % of total air pollution removed by trees • Current carbon storage • Carbon sequestered • Storm water reduction • Amenity valuation
Structural and functional value	• Replacement cost in £. • Carbon storage value in £. • Carbon sequestration value in £. • Pollution removal value in £.
Potential insect and disease impacts for any potential or existing pathogen including	Acute oak decline, Asian longhorn beetle, chalara dieback of ash, emerald ash borer, gypsy moth, plane wilt

Results – The structural resource

Land use

Based on the results of the randomly located plots, the i-Tree Eco model suggests that Oldham's land use can be described as follows.

The Urban area has the greatest variation in land use with the largest percentage being residential at 34.5%, this is followed by commercial/industrial (18.4%) and transportation (14.2%). The remaining percentages are made up of other land uses shown in Figure 1 (below).

The rural area is mainly classified as agriculture (72.6%) with very minimal residential (2.4%) which is expected due to the nature of rural areas.

The FCHO urban area is mainly made up of Residential (69.1%) and multi-family residential (18.4%).

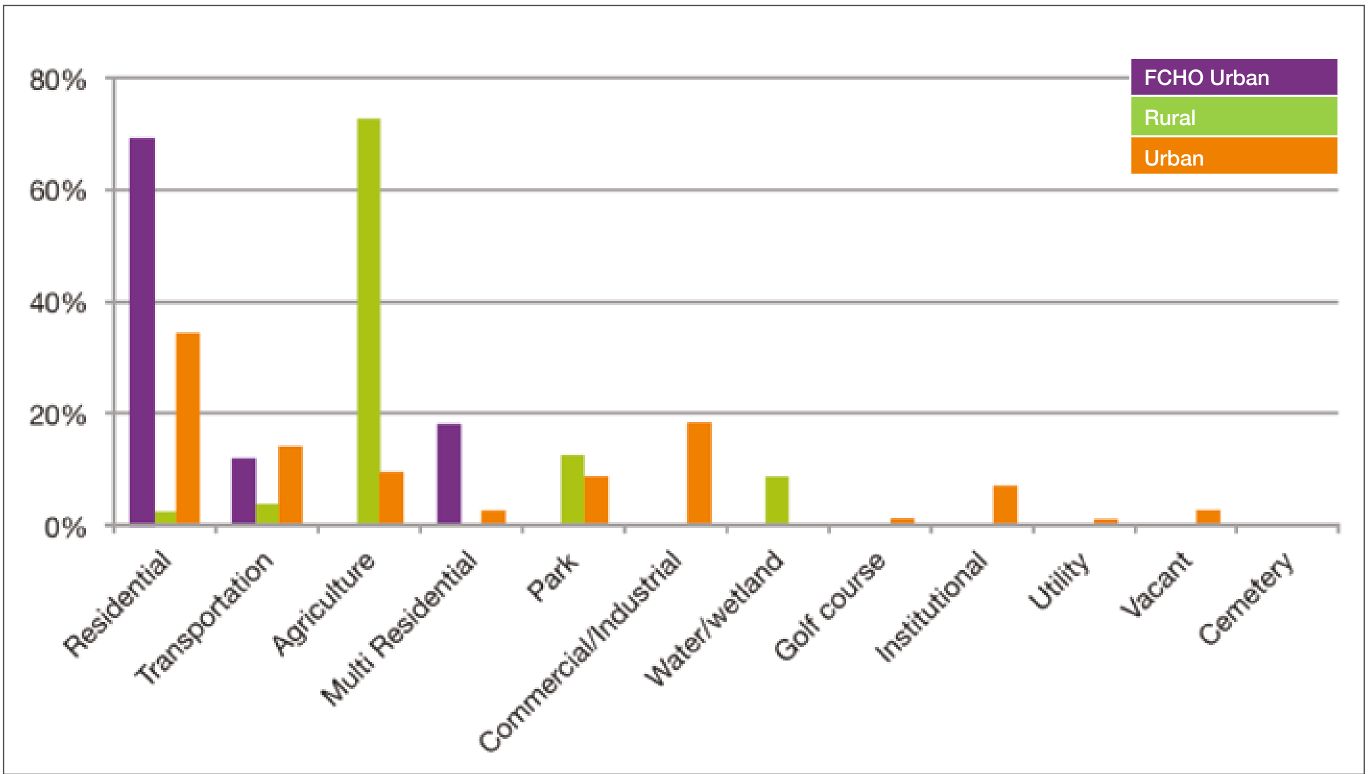


Figure 1: Land use for each area in Oldham

Royton

Royton

Oldham

Ground cover

Ground cover refers to the various surfaces found within the plot area. For example, the ground cover for a plot located within an industrial estate will have a 'commercial' land use, but it will also have various ground cover types present within it, such as grass, tarmac and concrete.

There may also be a percentage of the ground cover which is covered by an existing tree canopy, and a percentage of the ground which could theoretically be used for new tree planting. The i-Tree Eco assessment identified the following ground cover percentages in Oldham.

In Oldham 60.5% of ground cover is classified as grass. Of this 26.7% is classified as maintained grass and 33.8% classified as wild grass. FHCO urban has 31.2% of its ground cover classified as maintained grass with urban Oldham (16.2%) having a smaller percentage, rural Oldham has a maintained grass cover of 31.9%.

The percentage of land use classified as wild grass varies significantly between FCHO urban (0.3%), urban Oldham (11.7%) and rural Oldham (47.1%).

A total of 21.5% of ground cover in Oldham is impermeable. This is classified as, building, tarmac or cement. Of this ground cover classification 13.5% is either tarmac or cement and 8.0% buildings. There is little variance between FCHO urban (30.4%) and urban Oldham (32.4%) in ground cover classified as either cement or tarmac.

Rural Oldham has very little cement or tar cover (2.7%). There is some variance between FCHO urban (30.1%) and urban Oldham (21.3%) of ground cover classified as building.

A percentage of ground cover in Oldham (3.3%) is classified as bare soil but the individual areas are quite similar in size, FCHO urban (3.7%), urban Oldham (4.0%) and rural Oldham (2.9%).

Tree cover in Oldham is 11.8% with a relatively small percentage difference between FCHO urban (14.4%), urban Oldham (13.5%) and rural Oldham (10.0%). This can be compared with the tree cover found in other UK studies with caution. Many of these other studies have used aerial imagery and have also included shrubs as part of the canopy cover estimates. However, the tree cover in the London i-Tree project was 13.6%, this suggests that tree cover in Oldham is quite similar to tree cover to London. Tree cover in FCHO areas is also marginally higher than the over-all urban tree cover figure.

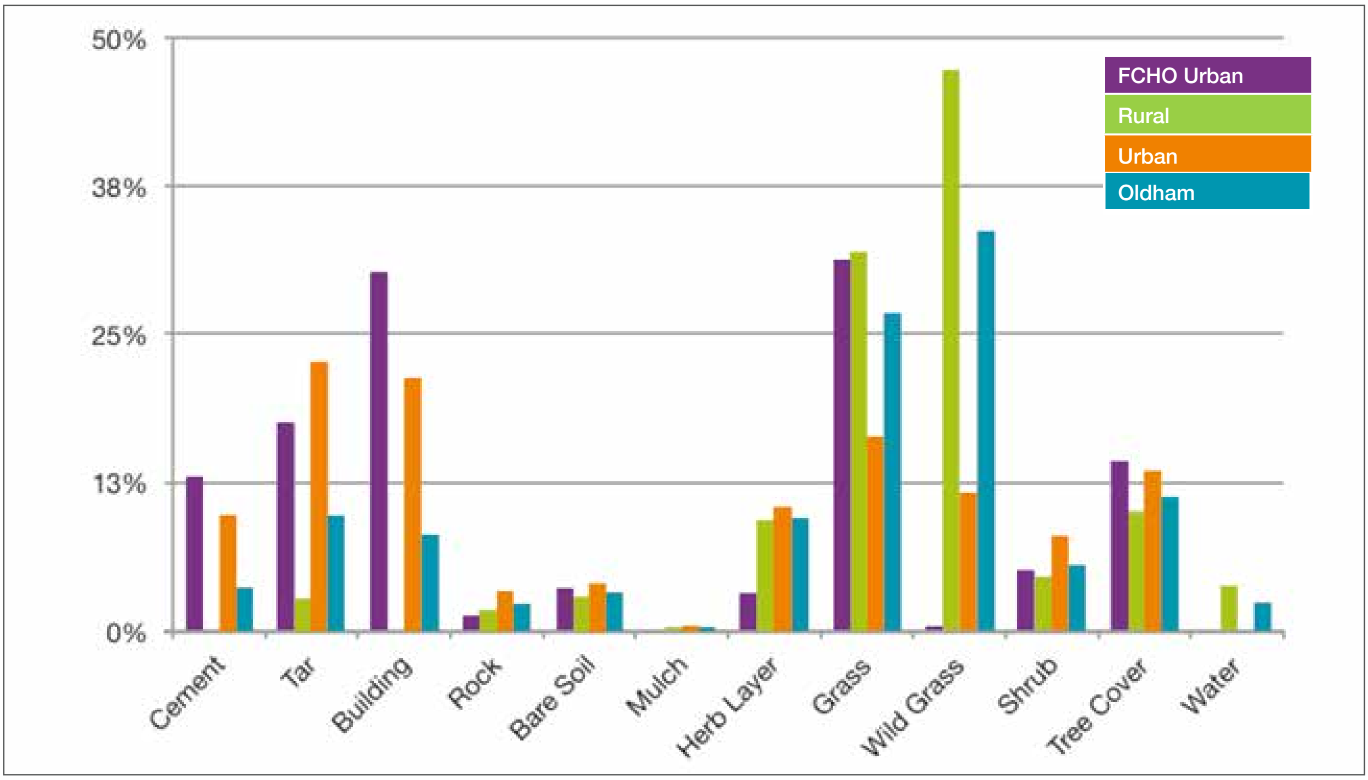


Figure 2: Ground cover in Oldham

The structure of Oldham's tree resource

Tree density

The tree density in Oldham is 33 trees per ha. This is lower than densities recorded for other i-Tree surveys (see table 3 below) and the UK average for towns and cities of 58 trees per ha[12].

The three most common species across Oldham are Alder (Alnus glutinosa) at 24%, Ash (Fraxinus excelsior) at 12.3% and Larch (Larix kaempferi) at 7.1%.

In FCHO Urban, Cypress (Cypress spp), Sycamore (Acer psedoplatanus) and Maple (Acer spp) are the three most commonly recorded trees with 12.5%, 10.0% and 7.5% of the population respectively.

In urban Oldham, Alder (Alnus glutinosa), Ash (Fraxinus excelsior) and Norway Spruce (Picea abies) are the three most commonly recorded trees with 15.8%, 8.3% and 6.4% of the population respectively.

However, it needs to be noted that the Norway Spruce recorded in this survey were smaller trees so despite their population they are not necessarily amongst the most significant trees (tree numbers combined with canopy size and leaf area). This aspect is discussed in more detail in the following section on Importance Value and Leaf Area.

In rural Oldham, Alder (Alnus glutinosa), Ash (Fraxinus excelsior) and Larch (Larix kaempferi) are the three most commonly recorded trees with 31.6%, 15.8% and 13.2% of the population respectively.

For species composition see figures 3, 4 and 5 below. Full details of tree composition for each species are given in Appendix III.

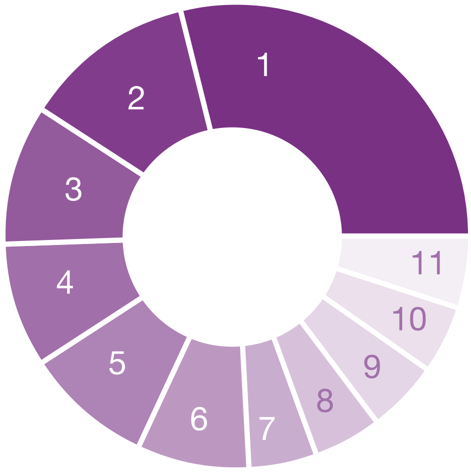
	Oldham	Greater London	Torbay	Glasgow
Study Area (ha)	14007	159470	6375	17643
Urban Tree Cover (%)	12	14	12	15
Trees (per ha)	33	53	105	112

Table 3: Comparison of tree densities from other i-Tree surveys

Ash (Fraxinus excelsior)

[12] Britt and Johnston 2008

Figure 3: Species composition for FCHO

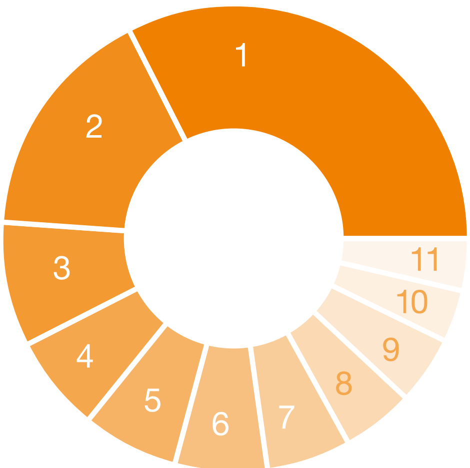


1	All other species	30%
2	Cypress spp	12.5%
3	Sycamore	10%
4	Maple spp	9%
5	Wild cherry	9%
6	Goat willow	8%
7	Japanese maple	5%
8	Ash	5%
9	London plane	5%
10	Japanese Cherry	5%
11	Whitebeam	5%


Sycamore


Wild cherry

Figure 4: Species composition for urban Oldham

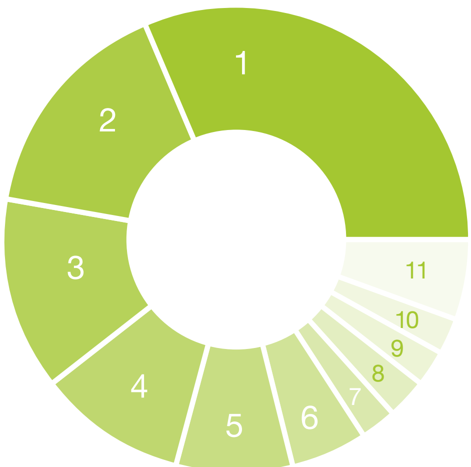


1	All other species	35.1%
2	Alder	15.8%
3	Ash	8.3%
4	Norway spruce	6.4%
5	Black poplar	6.4%
6	Wild cherry	6%
7	Goat willow	5.7%
8	Corsican pine	4.9%
9	English Oak	4.5%
10	Sycamore	3.4%
11	White willow	3.4%


Norway Spruce

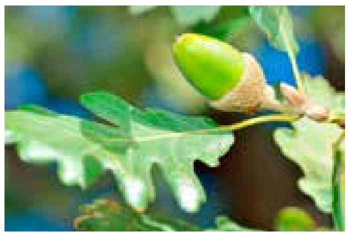

Black poplar

Figure 5: Species composition for rural Oldham



1	Alder	31.6%
2	Ash	15.8%
3	Larch	13.2%
4	Hawthorn	10.5%
5	Corsican pine	7.9%
6	Sycamore	5.3%
7	Birch	2.6%
8	Beech	2.6%
9	Spruce	2.6%
10	English oak	2.6%
11	All other species	5.3%


Hawthorn


English oak

Origin of species

Figure 6 (below) shows percentages for each area within each of the four continents from which the 59 species found in the survey originate. Across Oldham around 14% of the species recorded are of European origin.

Note: The + sign indicates that the species is native to another continent other than the continents listed in the grouping. For example, Europe and Asia + would indicate that the species is native to Europe, Asia, and one other continent.

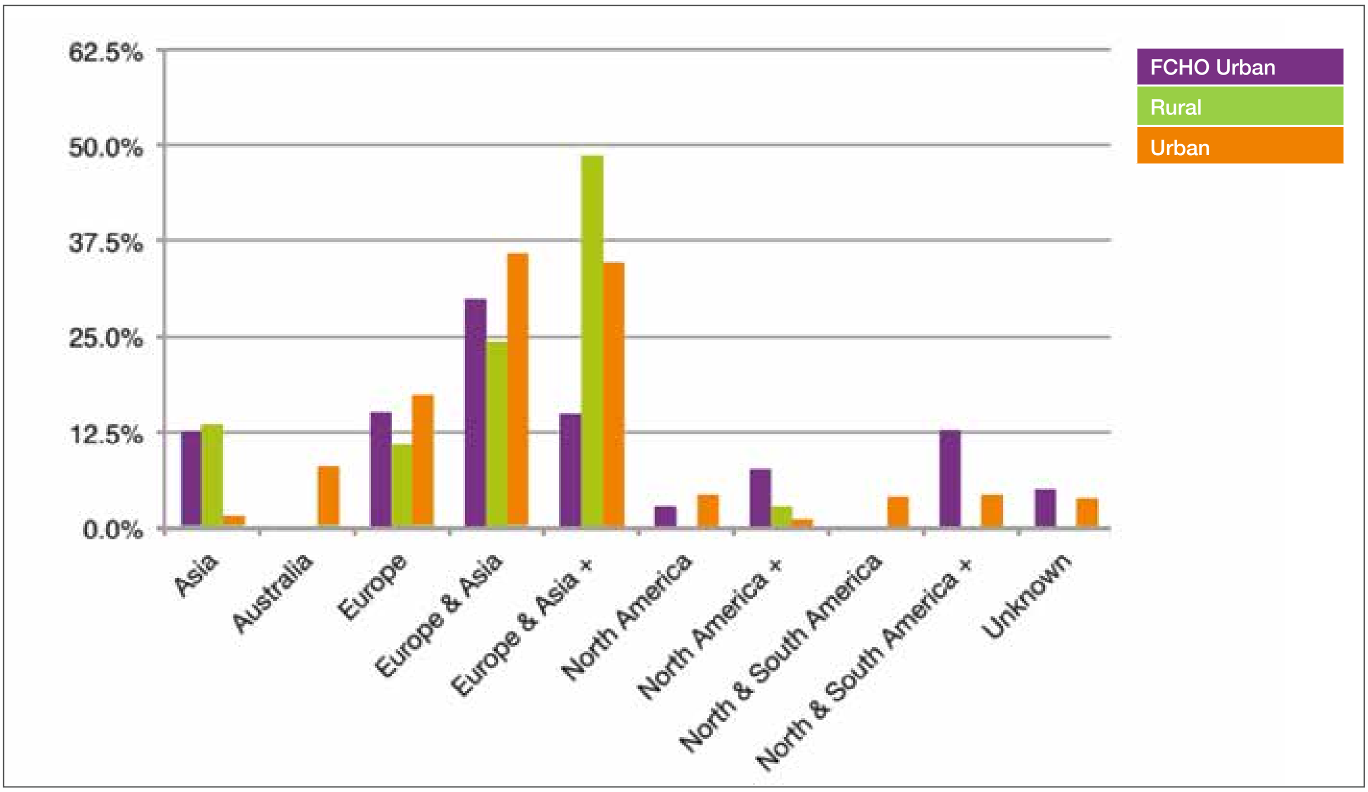


Figure 6: Origin of tree species

Tandle Hill Country Park

Size class distribution

Size class distribution is another 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.

In this survey trees were sized by their stem diameter at breast height (dbh) at 1.3m. Figure 7 (below) illustrates the size range of trees within Oldham from tree diameters at breast height (dbh).

The majority of trees within Oldham are within the lowest size categories, 72% of the trees recorded have a dbh of less than 30cm, whilst around 40% of the trees have diameters less than 15cm.

Across Oldham approximately 28% of the tree population is larger than 30cm dbh. This compares favourably with cities and towns in other regions of England, where the Trees in Towns 2 survey found that on average only 10–20% of trees have a dbh that is greater than 30cm[13].

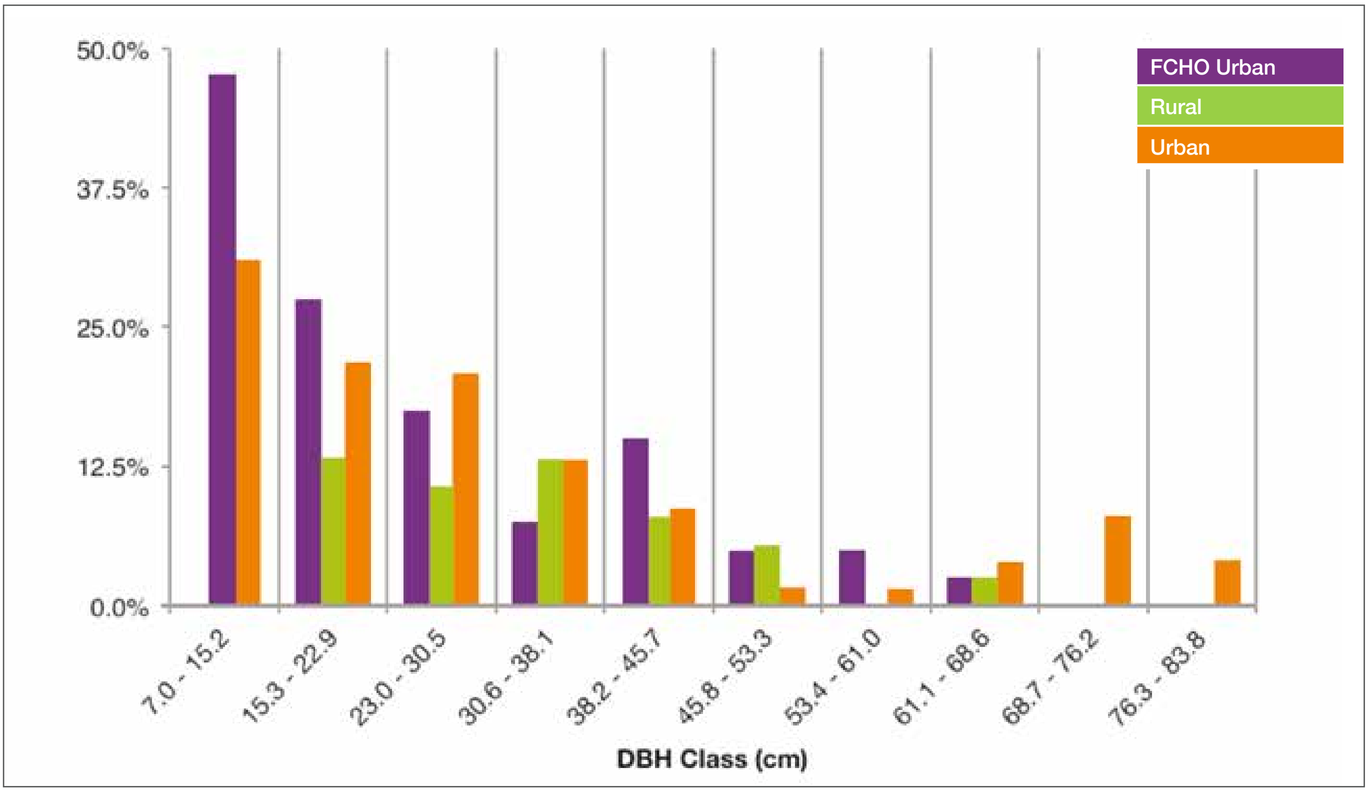


Figure 7: Size class distribution

The number of trees in each dbh class declines successively and trees with dbh's higher than 60cm make up just over 2% of the tree population.

The size distribution of trees is an important consideration for a resilient population. Large mature trees offer unique ecological roles not offered by smaller or younger trees[14]. Furthermore, older trees with larger crowns provide greater benefits than a similar number of smaller sized trees.

To maintain or increase a level of mature trees, young trees are needed to restock the larger size classes (with surplus) to include planning for mortality.

Urban Forests are unique and there is no 'one size fits all' target distribution. However, the proportion of trees with diameters between 45cm and 80cm in Oldham is considered low, suggesting that there may be a shortage of large sized trees in the near future.

[13] Britt and Johnston 2008
[14] Lindenmayer, Laurance & Franklin 2012

Importance value and leaf area

Tree benefits are directly linked to leaf surface area. The greater the amount of healthy leaf surface area available the greater the benefits provided.

The dominance value of a tree species within any tree population is arrived at by assessing the abundance of that species coupled with the gross leaf surface area of that species.

Taking into account the leaf area and relative abundance of a species i-Tree Eco is able to calculate the dominance value for each species ranking them in respect of their importance for the delivery of benefits.

Trees cover approximately 11.8% of Oldham[15] and provide 64,433 square kilometres of leaf area. The total leaf area is greatest in rural areas (approximately 38,000 square kilometres), followed by urban areas (approximately 24,000 square kilometres) and FCHO urban (approximately 2,500 square kilometres). When shrubs are included to provide total canopy cover this figure increases to 16.9%.

Across Oldham the three most important species in terms of leaf area are Alder (Alnus glutinosa), Ash (Fraxinus excelsior) and Larch (Larix kaempferi), see table 4 (below). Collectively these three species represent 43.4% of the total tree population of Oldham and provide approximately 41% of the total leaf area.

The percentage a species represents numerically within a population does not always reflect its dominance value. For example Sycamore (Acer psuedoplatanus), in Oldham, represents just 4.6% of the total population yet provides 16.5% of the total leaf area and has a dominance value of 21.1. Hawthorn (Crateagus monogyna) represents 7% of the total population yet only has 3.8% of the total leaf area and has an importance value (IV) of 10.8.

Tree species such as hawthorn (Crateagus monogyna) have a much smaller leaf area compared to their percentage of the population as they are smaller in stature. This is reflected in their respective dominance values.

Other tree species make a combined contribution to the leaf area in Oldham. Poplar (Populus nigra) 2.7% of the population, Beech (Fagus sylvatica) 2.6% of the population, Mountain Ash (Sorbus aucuparia) 2.4% of the population and Birch (Betula pendula) 2.7% of the population, contribute 11.3% of the leaf area and have a collective importance value of 21.8.

The percentage of a species in the population does not always reflect the importance of particular benefits that species provides. In Oldham Sycamore (Acer psuedoplatanus) represents just 4.6% of the population yet is the most highly rated species in terms of annual gross carbon sequestration and is again the most highly rated in terms of oxygen production.

A high dominance value does not necessarily imply that these trees should form the core of any future planting strategy. It shows which species are currently delivering the most benefits based on their presence in the total population and the leaf area they provide.

These species currently dominate the urban forest structure of Oldham because they are the most abundant and have the largest leaf areas. They are therefore the most important in delivering existing benefits. Future planting programmes should take into account the benefits required in the future based on a local assessment of priorities and issues such as climate change and overall tree population sustainability and resilience.

Larger trees have a greater functional value and provide increased benefits to the residents of Oldham. It has been estimated in previous studies 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.

[15] The figure will vary slightly (within 1%) depending on how the strata are rounded and averaged

Pingot Quarry, Cromptom

Species	% Population	% Leaf Area	Importance Value
Alder	24.00	12.70	36.70
Ash	12.30	11.60	23.90
Larch	7.10	16.80	23.90
Sycamore	4.60	16.50	21.10
Corsican Pine	6.50	6.30	12.70
Hawthorn	7.00	3.80	10.80
Black Poplar	2.70	3.10	5.90
Beech	2.60	2.90	5.50
Rowan	2.40	3.00	5.40
Birch	2.70	2.30	5.00

Table 4: The ten most dominant or 'important' trees in Oldham

Results – Ecosystem services resource

Air pollution

Poor air quality is a common problem in many urban areas and along road networks. Air pollution caused by human activity has been a problem since the beginning of the industrial revolution. With the increase in population and industrialisation, and the use of transport based on fossil fuels, large quantities of pollutants have been produced and released into the urban environment. The problems caused by poor air quality are well known, ranging from human health impacts to damage to buildings.

Urban trees can help to improve air quality by reducing air temperature and by directly removing pollutants from the air[16]. They intercept and absorb airborne pollutants through leaf surfaces[17].
By removing pollution from the atmosphere, trees reduce the risks of respiratory disease and asthma, thereby contributing to reduced health care costs[18].

Table 5, outlines the total air pollution removal by trees and shrubs actually measured in each of the three areas.

Area	Air pollution removed (tonnes)	Value (£)
FCHO Urban	2.04	£32,251.98
Rural	39.46	£624,974.00
Urban	23.33	£369,423.50
Total	**64.82**	**£1,026,649.00**

Table 5: The comparative values for air pollution for all areas

Some trees also emit volatile organic compounds (VOCs) that can contribute to low-level ozone formation; however integrated studies have revealed that an increase in tree cover leads to a general reduction in ozone through a reduction in the urban heat island effect[19]. Since different tree types may emit VOCs at different levels, species choice is an important consideration.

A study by Manchester University developed an Urban Air Tree Quality Score as a decision support tool for this purpose[20].

Figure 8: shows the values for the removal of pollutants by trees across Oldham's urban forest and the estimated economic value of this removal. Ozone is the pollutant most removed by the trees with an annual mean removal of 53067kg whilst the removal of air pollution by PM2.5s has the highest associated monetary value at £1,215,908.00.

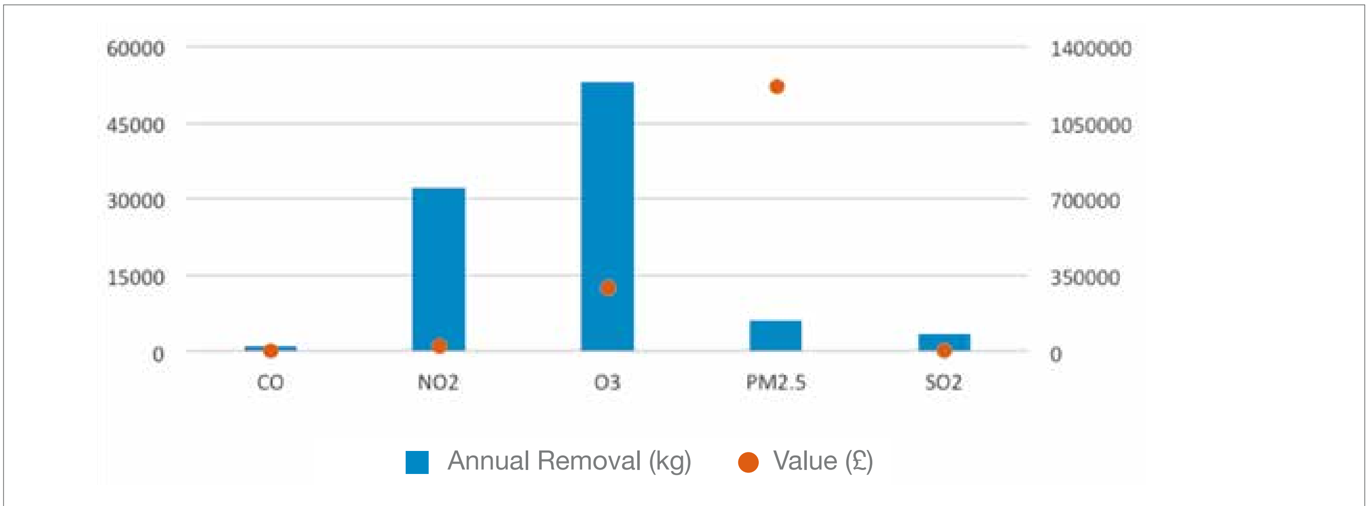


Figure 8: The value and quantity of the pollutants removed annually for Oldham

[16] Tiwary et al 2009
[17] Nowak et al 2000
[18] Peachey et al., 2009, Lovasi et al., 2008
[19] Nowak et al 2006
[20] McDonald et al 2007

Carbon storage and sequestration

Trees can help mitigate climate change by sequestering atmospheric carbon as part of the carbon cycle and storing carbon in their structures in the long term. 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. Over the lifetime of a single tree, several tonnes of atmospheric carbon dioxide can be absorbed.

The carbon stored for all the trees sampled in Oldham is estimated at 66,508 tonnes with an associated economic value estimated at £4,246,000. The rural area stores the most carbon with 32,098 tonnes, followed by the urban area with 31,697.2 tonnes and the FCHO Urban area with 2,712 tonnes.

Figure 9: shows the ten most dominant species over each area regarding carbon storage. Sycamore comprises of the most carbon, accounting for an estimated 13,298 tonnes at a value of £848,944.00. The top 10 species contain 80.6% of the total carbon stored.

Figure 9: Ten most significant species for carbon storage for Oldham

The total estimated annual gross carbon sequestered by the sampled trees for all areas is 3,168 tonnes, with a CO_2 equivalent of 11,618 tonnes a year. The economic value of this is estimated at £202,255.00.

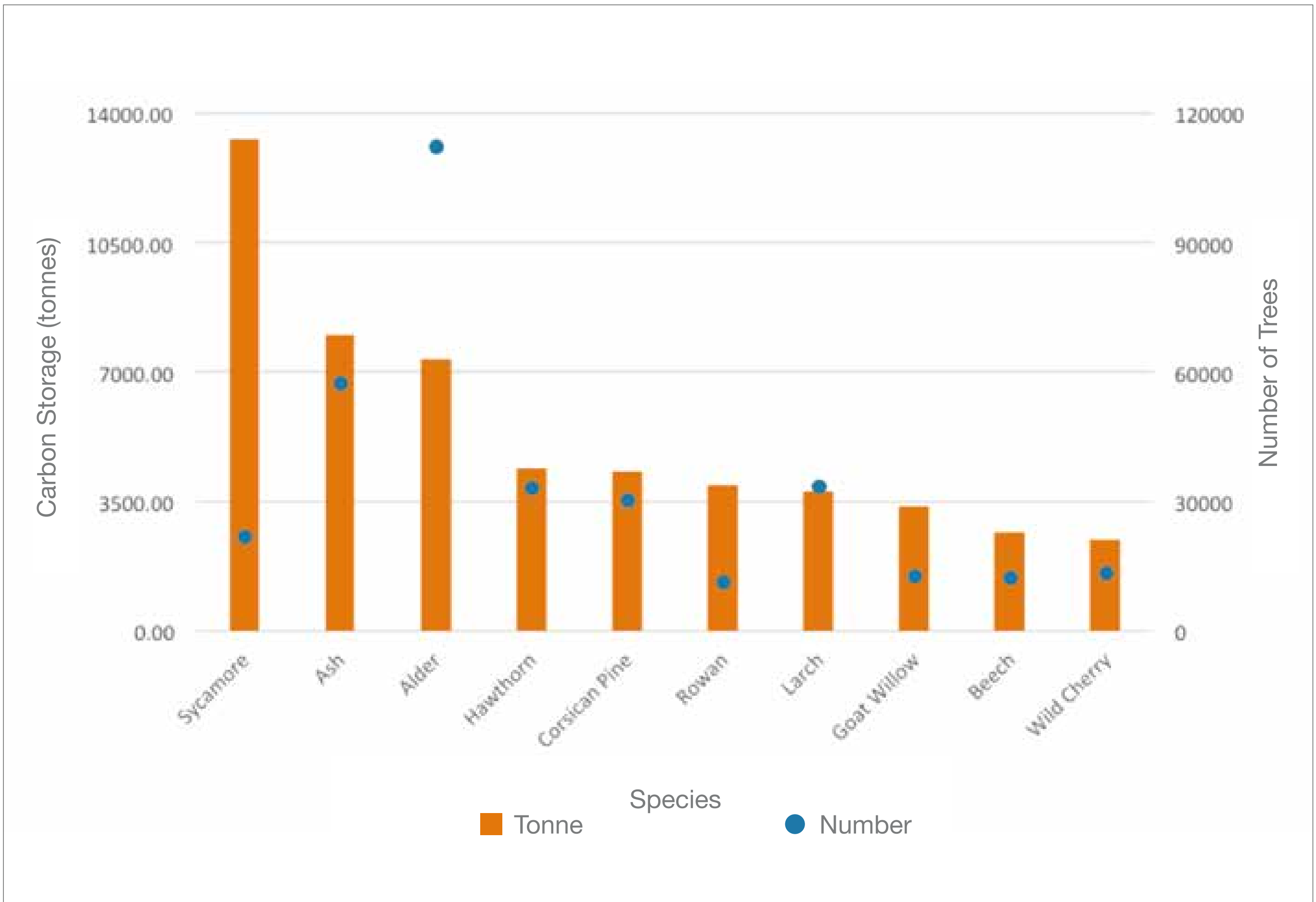


Figure 9: The ten most significant species for carbon storage for Oldham

Figures 10, 11 and 12 (below) show the top ten species which sequester the most carbon for each area. The rural area sequesters the most carbon in total annually at 1,502 tonnes. The most dominant species is Sycamore accounting for an estimated 354 tonnes annually.

In the urban area, Alder is the most dominant species regarding carbon sequestration at 186 tonnes annually; in total the urban area sequesters an estimated 1513 tonnes of carbon annually.
The total carbon sequestration for the FCHO Urban area is estimated at 153 tonnes annually. Sycamore is the most dominant species sequestering an estimated 27 tonnes annually.

Figure 10: Ten most significant species for carbon sequestration for the FCHO Urban area

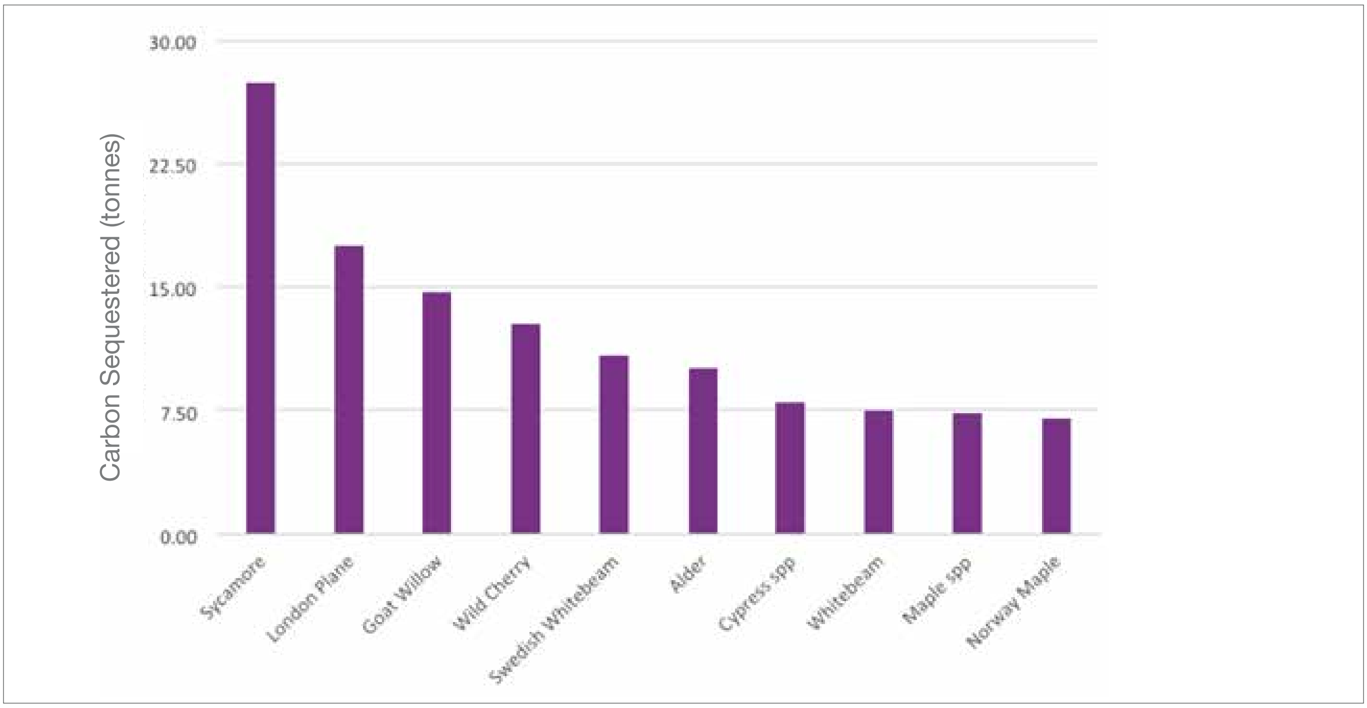


Figure 11: Ten most significant species for carbon sequestration for the rural area

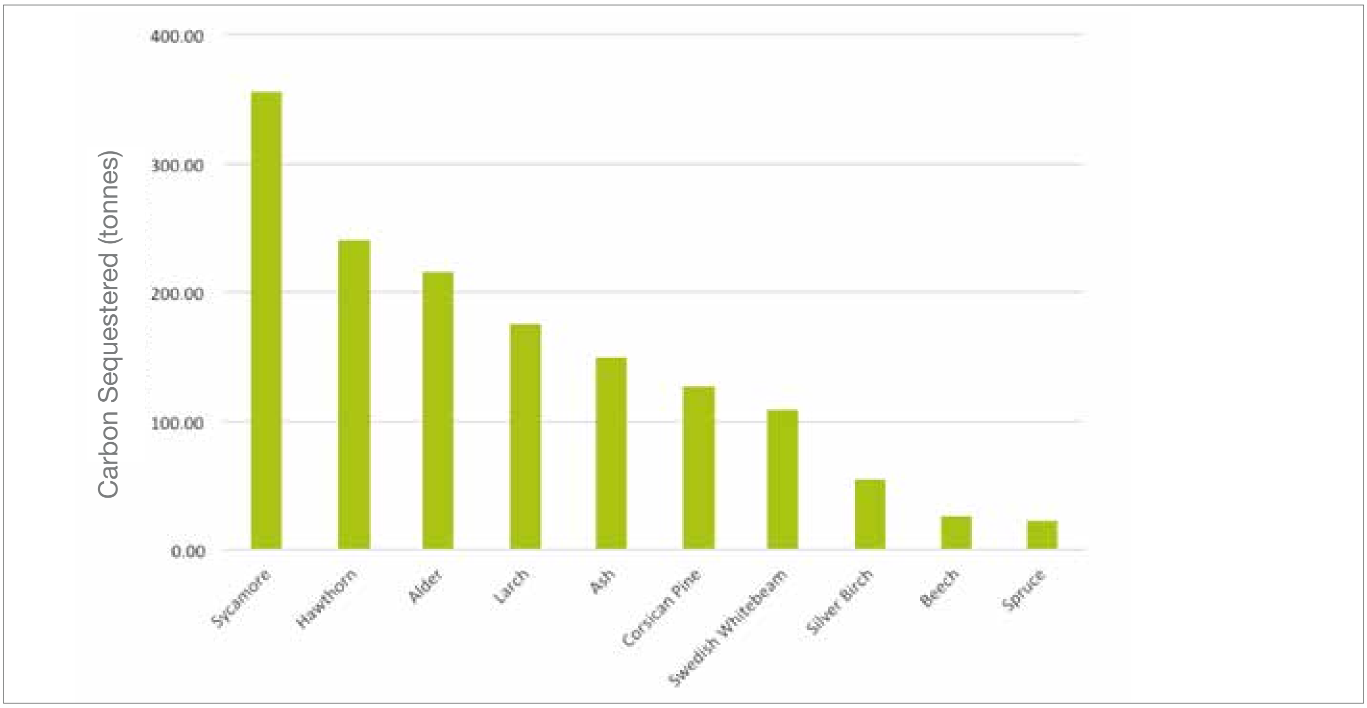


Figure 12: Ten most significant species for carbon sequestration for the urban area

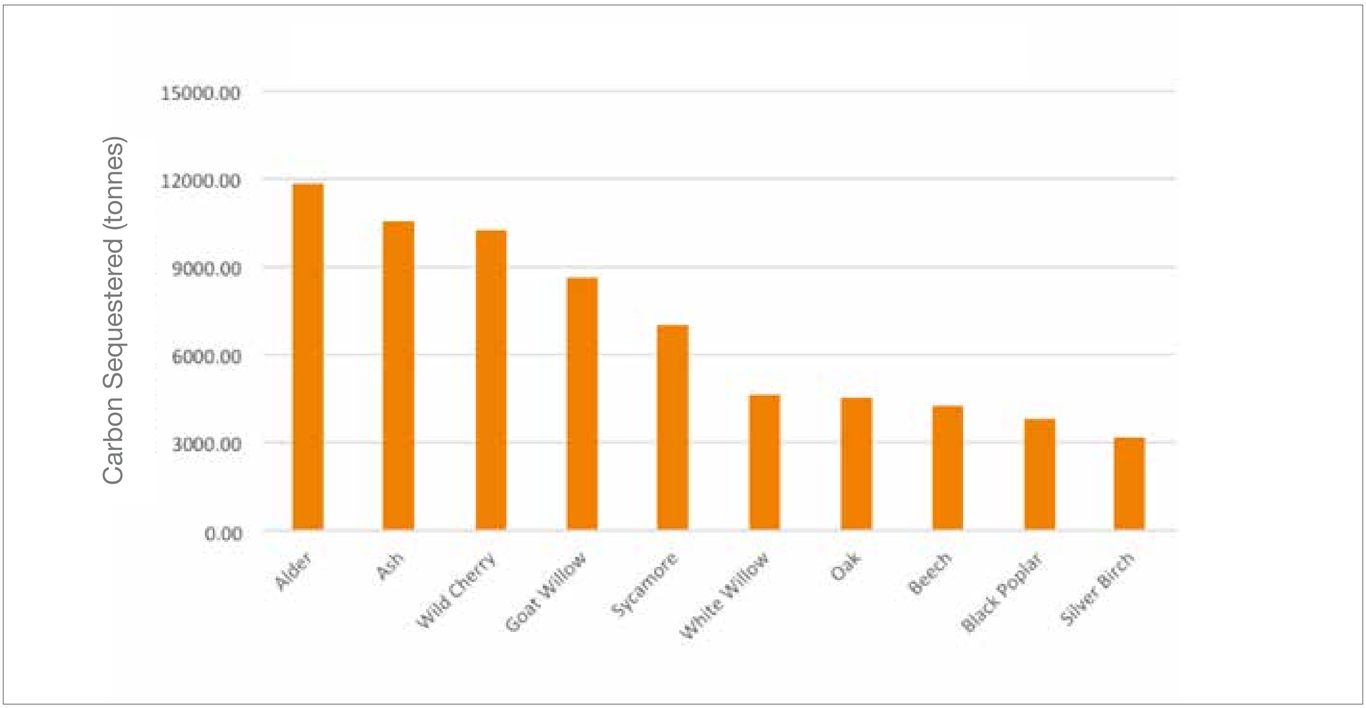


Table 6: Comparison for carbon storage and sequestration and the associated economic value for each area

Area	Carbon Storage (tonnes)	Value (£)	Carbon Sequestration (tonnes/yr)	Value (£)
FCHO Urban	2,711.50	£173,103.20	152.98	£9,766.42
Rural	32,098.20	£2,049,146.18	1,501.87	£95,879.26
Urban	31,697.20	£2,023,550.48	1,513.30	£96,608.88
Oldham	66,506.89	£4,245,799.86	3,168.15	£202,254.57

Stormwater runoff

Surface runoff can be a cause for concern in many areas as it can contribute to flooding and a source of pollution in streams, wetlands, rivers, lakes, and oceans. During precipitation events, a portion of the precipitation is 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 runoff [21].

In urban areas, the large extent of impervious surfaces increases the amount of runoff. However, trees are very effective at reducing surface runoff [22]. Trees intercept precipitation, while their root systems promote infiltration and storage in the soil.

The value for annual avoided stormwater runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. The i-Tree model estimates the avoided stormwater runoff monetary value by calculating the price as £1.516/m³.

As shown in Table 7 (below), the trees of Oldham help to reduce runoff by an estimated 202,680 m³ each year with an associated value of £307,333.00. The rural area helps to reduce the most runoff by approximately 123,382m³ a year with a monetary value of £187,089.00. This is followed by the urban area which is estimated to help reduce 72,931m³ of runoff each year, estimated at an associated economic benefit of £110,589.00 and the FCHO urban area which helps to reduce runoff by 6,367m³ a year with an associated monetary value of £9,655.00.

Table 7: The comparative values for avoided runoff for each study area

Area	Number of Trees	Leaf Area (ha)	Avoided Runoff (m³/yr)	Avoided Runoff Value (£/yr)
FCHO Urban	13,422	202.41	6,367.15	£9,654.80
Rural	253,266	3,922.34	123,381.60	£187,089.36
Urban	200,074	2,318.50	72,931.14	£110,588.94
Study Area	466,762	6,443.26	202,679.89	£307,333.10

[21] Hirabayashi (2012)
[22] Trees in Hard Landscapes (2014)

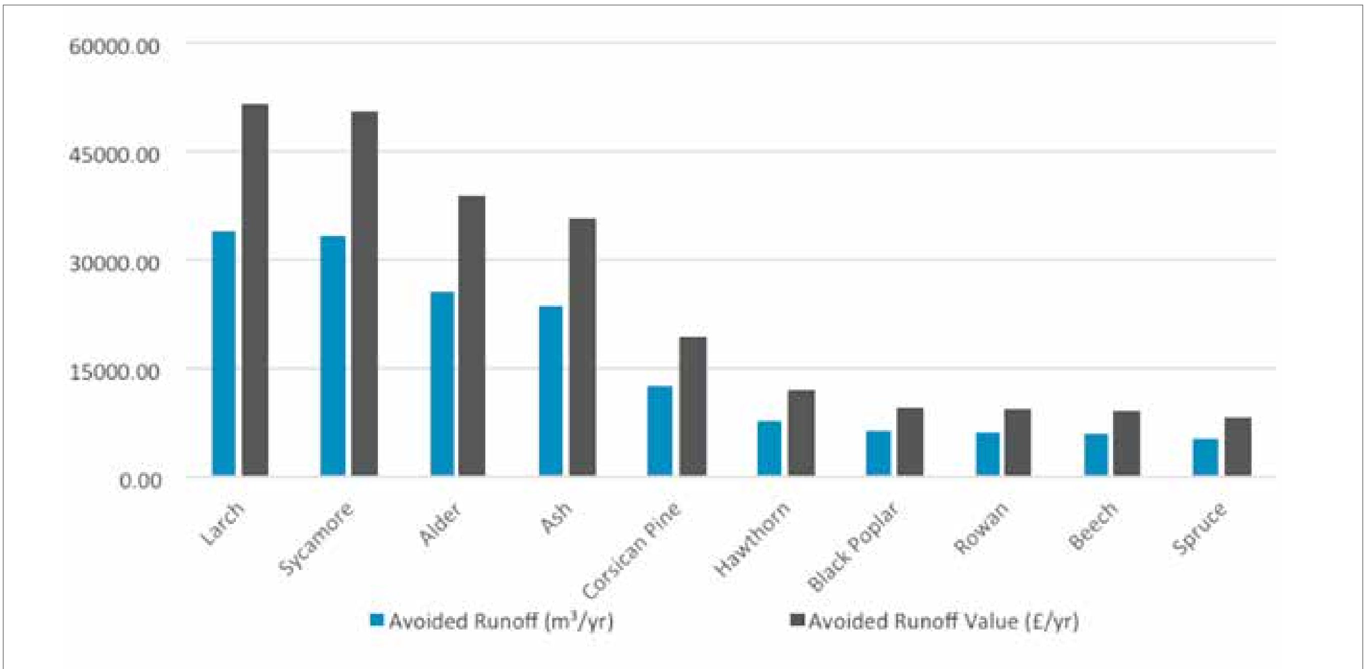
Figure 13 (below) shows the top ten species for Oldham in terms of avoided stormwater runoff and the associated monetary value of the service. Larch (Larix kaempferi), Sycamore (Acer pseudoplatanus) and Alder (Alnus glutinosa) are the three most dominant species. Together they consist of 166,185 individual trees and a combined leaf area of 2956 ha which accounts for an avoided run off of 92,981m³. The three species alone contribute £140,992.00 in value of avoided run off.

Larch (Larix kaempferi)

Sycamore (Acer pseudoplatanus)

Alder (Alnus glutinosa)

Figure 13: The top ten species for avoided runoff



Replacement cost

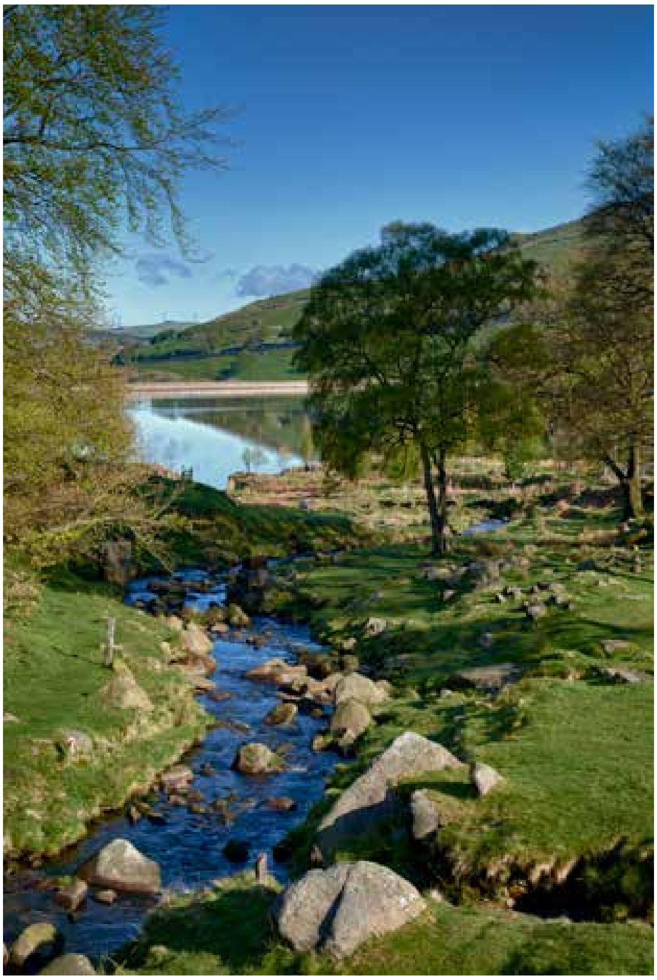
In addition to estimating the environmental benefits provided by trees the i-Tree Eco model also provides a structural valuation of the trees in the urban forest. In the UK this is termed the 'Replacement Cost'. It must be stressed that the way in which this value is calculated means that it does not constitute a benefit provided by the trees. The valuation is a depreciated replacement cost, based on the Council of Tree and Landscape Appraisers (CTLA) formulae[23]. The formula allows for tree suitability in the landscape and nursery prices.

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 14 below.

The total replacement cost of all trees in Oldham currently stands at £231million.

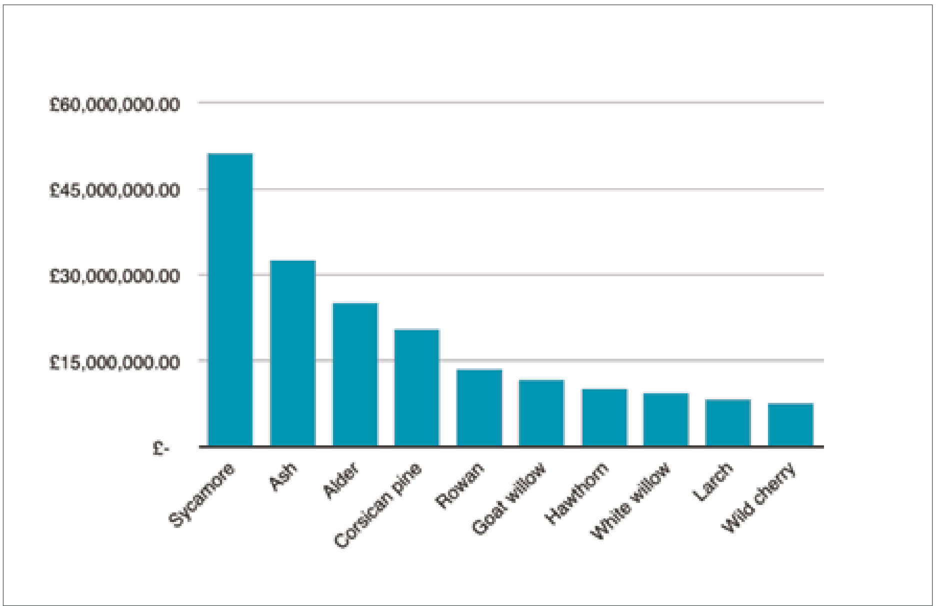
Sycamore is the most valuable species of tree, on account of both its size and population, followed by Ash and Alder. These three species of tree account for £108,423,000.00 (47%) of the total replacement cost of the trees in Oldham.

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



Dove Stone Reservoir, Greenfield

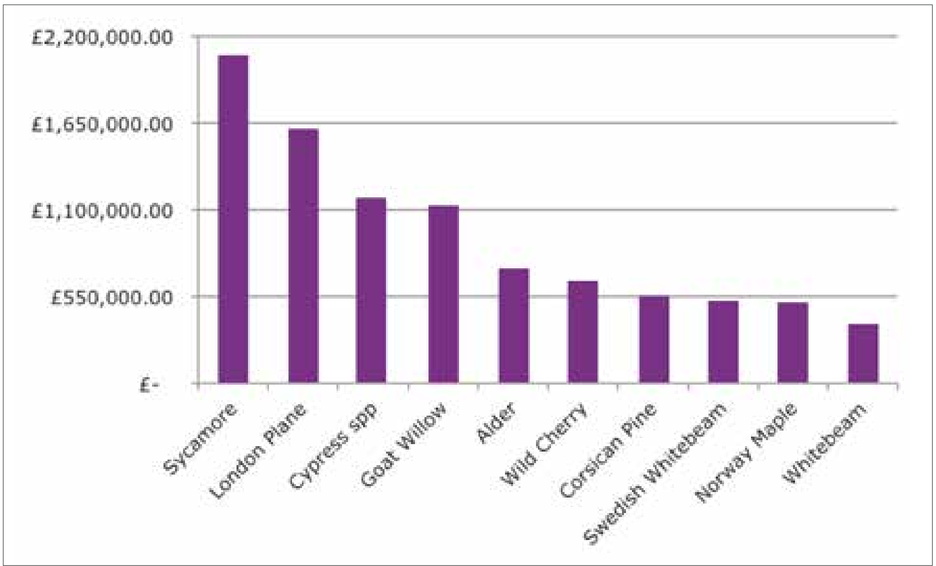
Figure 14: The ten most valuable tree species in Oldham



[23] Hollis 2007

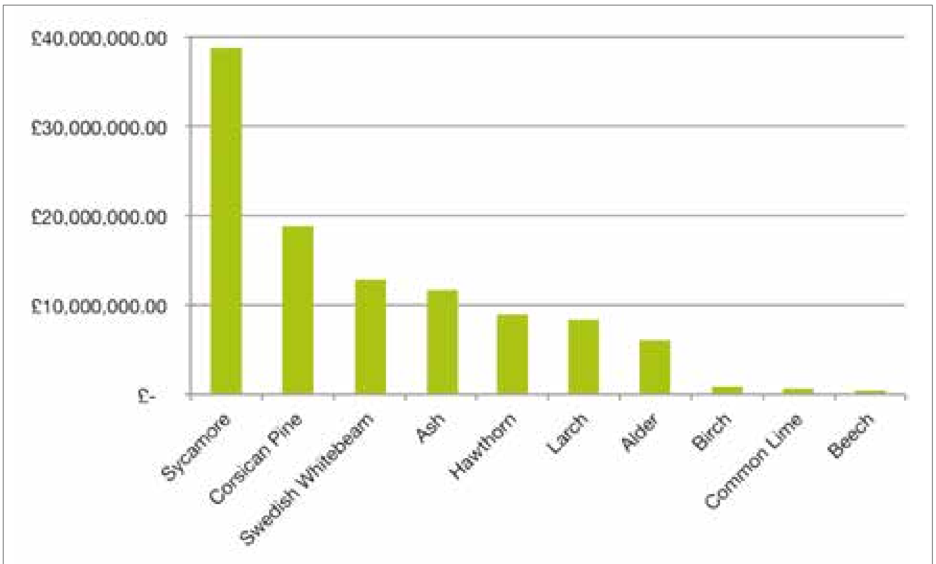
The replacement costs for the ten top trees in each area are shown in figures 15, 16 and 17 below. Sycamore is the most valuable species of tree in the FCHO Urban area, followed by London Plane and Cypress spp. These three species of tree account for £4,873,323.00 (46%) of the total replacement cost of the trees in FCHO urban (£10,552,628.00) and 2.1% of the total replacement cost in Oldham.

Figure 15: The ten most valuable tree species in the FCHO Urban area



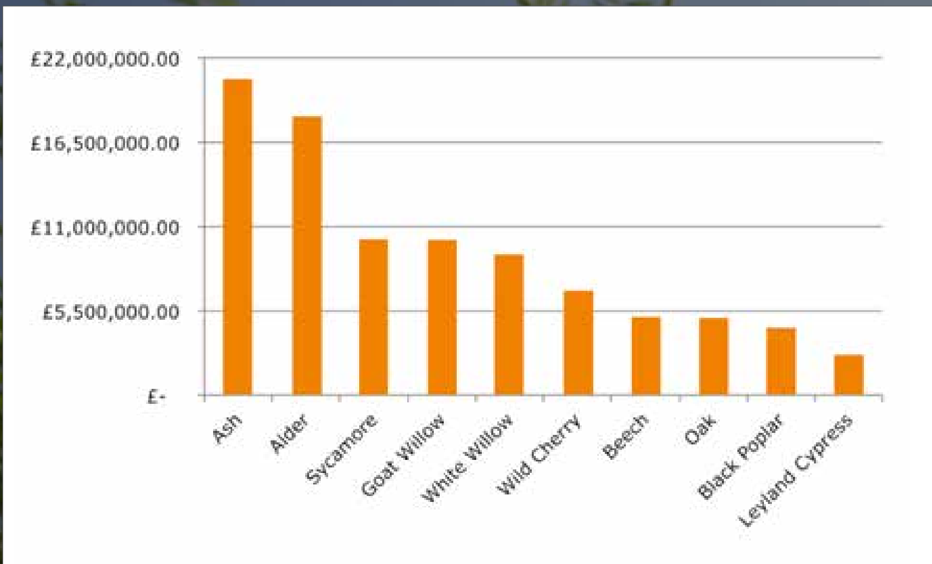
Sycamore is the most valuable species of tree in the rural area, followed by Corsican Pine and Swedish Whitebeam. These three species of tree account for £70,381,339.00 (65%) of the total replacement cost of the trees in the rural area (£107,726,819.00) and 30.5% of the total replacement cost in Oldham.

Figure 16: The ten most valuable tree species in the rural area



Ash is the most valuable species of tree in the urban area, followed by Alder and Sycamore. These three species of tree account for £48,987,944.00 (43.5%) of the total replacement cost of the trees in the urban area (£112,703,770.00) and 21.2% of the total replacement cost in Oldham.

Figure 17: The ten most valuable tree species in the Urban area



CAVAT – The amenity value of Oldham's trees

Capital Asset Valuation for Amenity Trees (CAVAT) is a method developed in the UK to provide a value for the public amenity that trees provide, to add another dimension to the utilitarian approach which is adopted in the CTLA method[24]. Both methods offer a valid analysis.

CAVAT allows the value of Oldham's trees to include a social dimension by valuing the visual accessibility and prominence within the overall urban forest. Particular differences to the CTLA method includes the addition and consideration of the Community Tree Index (CTI), which adjusts the CAVAT assessment to take account of the greater amenity benefits of trees in areas of higher population density, using official population figures.

Method

An amended CAVAT 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 required:

- The current unit value
- Diameter at Breast Height (DBH)
- The CTI (Community Tree Index) rating, reflecting local population density
- An assessment of accessibility
- An assessment of overall functionality, (that is the health and completeness of the crown of the tree)
- An assessment of safe life expectancy

The current unit value is determined by the CAVAT steering group and is currently set at £15.88 (LTOA 2012).

DBH is taken directly from the field measurements. The CTI rating is determined from the approved list (LTOA 2012) and is calculated on a borough by borough basis.

Accessibility, ie the ability of the public to benefit from the amenity value of tree, was generally judged to be 100% for trees in parks, street trees and other open areas, and was generally reduced for residential areas and transportation networks to 60% (increased to 100% if the tree was on the street), to 80% on institutional land uses and to 40% on agricultural plots. A full list is given in table 8 below.

[24] For full details on the CAVAT system see: www.ltoa.org.uk/resources/cavat.
For details of CTLA see Hollis (2007).

Table 8: Accessibility weightings for CAVAT

Safe Life Expectancy assessment was intended to be as realistic as possible, but based on existing circumstances. For full details of the method refer to LTOA (2010).

Land Use	Street Tree	Accessibility %
Agriculture	Yes	100
Agriculture	No	40
Cemetery	Yes	100
Cemetery	No	80
Commercial/Industrial	Yes	100
Commercial/Industrial	No	40
Golf Course	Yes	100
Golf Course	No	60
Institutional	Yes	100
Institutional	No	80
Multi-family Residential	Yes	100
Multi-family Residential	No	80
Other	Yes	100
Other	No	60
Park	Yes	100
Park	No	100
Residential	Yes	100
Residential	No	60
Transportation	Yes	100
Transportation	No	40
Utility	Yes	100
Utility	No	20
Vacant	Yes	100
Vacant	No	80
Water/Wetland	Yes	100
Water/Wetland	No	60


Dogford Park, Royton

CAVAT assessment

Functionality was calculated directly from the amount of canopy missing.

The particular nature of local street trees, local factors and choices could not be taken into account as part of this study. The value should reflect the reality that street trees have to be managed for safety. They are frequently crown lifted and reduced (to a greater or lesser extent) and are generally growing in conditions of greater stress than their open grown counterparts. As a result they may have a significantly reduced functionality under the CAVAT system.

According to the CAVAT valuation, Oldham's urban forest is estimated to be worth an estimated £1.8 billion. As an asset to Oldham, the above figure is equivalent to nearly 16 times the cost of constructing City of Manchester Stadium.

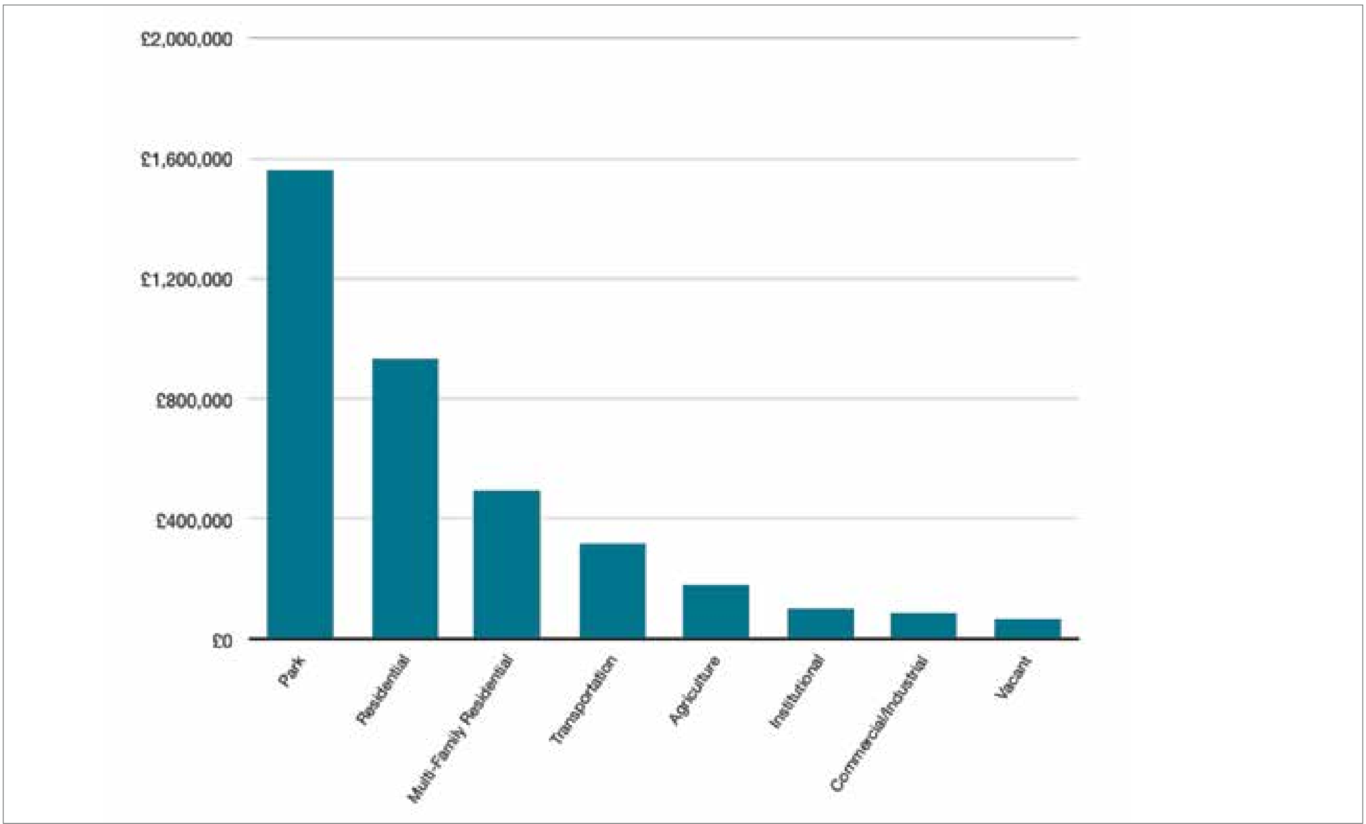
The Alders of Oldham hold the highest CAVAT value Table 9, representing nearly 24% of the total of all the trees.

Table 9: % CAVAT by Genus top 20

Scientific name	Percentage	Value by species	Value across Oldham
Alnus	**16.0%**	**£876,501.52**	**£425,698,919.16**
Fraxinus	**9.0%**	**£627,414.47**	**£304,722,414.49**
Prunus	**8.2%**	**£334,594.69**	**£162,505,819.36**
Salix	**8.7%**	**£217,295.63**	**£105,536,059.61**
Quercus	**3.8%**	**£208,935.27**	**£101,475,601.62**
Fagus	**3.2%**	**£166,878.13**	**£81,049,303.45**
Sorbus	**4.4%**	**£138,509.61**	**£67,271,295.50**
Betula	**2.9%**	**£136,806.72**	**£66,444,232.40**
Cupressocyparis	**2.6%**	**£130,544.12**	**£63,402,617.28**
Picea	**5.8%**	**£120,959.70**	**£58,747,659.38**
Crataegus	**4.7%**	**£110,461.93**	**£53,649,106.43**
Acer	**6.4%**	**£101,501.00**	**£49,296,968.32**
Populus	**5.2%**	**£83,714.82**	**£40,658,582.07**
Ilex	**2.3%**	**£82,215.98**	**£39,930,627.32**
Cupressus	**2.0%**	**£63,329.94**	**£30,758,060.92**
Eucalyptus	**0.3%**	**£56,842.95**	**£27,607,460.44**
Larix	**2.0%**	**£43,672.39**	**£21,210,787.14**
Pinus	**5.2%**	**£38,429.61**	**£18,664,479.92**
Rhododendron	**0.6%**	**£35,991.05**	**£17,480,121.28**
Sub Total	**93.6%**	**£3,574,599.54**	**£1,736,110,116.09**
Other species	**6.4%**	**£110,452.62**	**£53,644,586.05**
Total	**100.0%**	**£3,685,052.16**	**£1,789,754,702.14**

The single most valuable tree encountered in the study was also an Ash, situated in plot 22, estimated have an amenity value of £203,714.50. Parks hold most of the amenity value of trees, with the total value of trees within this land use type estimated at approximately £1.5 million in the plots sampled. This is 42% of the amenity value held by Oldham's trees (Figure 18) illustrating the importance of Oldham's parks to its inhabitants. Residential areas are also important as they hold 25% of the amenity value totalling £926,000.

Figure 18: CAVAT Value by Land Use.
Land use types where no trees were found are omitted.



Above: Alexandra Park, boating lake, Oldham. Opposite: Daisy Nook Country Park, Failsworth.

Tree diversity

Diversity in the urban forest has two main components, the number of species present and the genetic diversity of the individual species present. This diversity reduces the potential impact from threats such as pest and disease and climate change and increases the capacity of the tree population to deliver ecosystem services.

Within the urban forest patterns of diversity vary with biophysical and socioeconomic factors[25] and also by land use[26].

Although i-Tree Eco does not yet calculate a valuation of biodiversity it does provide an indication of the tree species diversity using various diversity indexes (Shannon, Simpson and Menhinick). The diversity indices for Oldham are outlined in table 10 below.

Table 10: Tree diversity indices for Oldham

Area	Species	Species/ha	Shannon	Menhinick	Simpson	Evenness
FCHO Urban	20	14.50	2.90	3.20	24.40	1.00
Rural	12	9.00	2.10	1.90	18.00	0.80
Urban	51	8.30	3.30	3.10	7.00	0.80
Oldham	59	6.70	3.40	3.20	18.70	0.80

Daisy Nook Country Park, Crime Lake

Daisy Nook Country Park

[25] Escobedo et al 2006, Kendal et al 2012
[26] Pauleit et al 2002, Saebo et al 2003, Sjoman and Busse Neilson 2012

Notes for Table 10:

Species/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 low sensitivity to sample size.

Menhinick: is the Menhinick'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 Simpson'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 comparison between land use types.

Evenness: is the Shannon 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.

Diversity is important because the diversity of species within Oldham (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 total of 59 different species were sampled in Oldham with approximately 6.7species per hectare. A greater number of species were sampled in urban Oldham (51) than in rural Oldham (12) or FCHO urban (20) although the different species per hectare were greater in FCHO urban (14.5) and rural Oldham (9.0) than that found in urban Oldham (8.3).

On the Shannon diversity index (where 1.5 is considered low and 3.5 is high) urban Oldham (3.3) demonstrated a high level of species diversity. FCHO urban (2.9) and rural Oldham (2.1) both have good diversity scores. Using the same index Oldham (3.4) showed higher levels of species than other comparable studies carried out in the UK, Torbay (3.32), Edinburgh (3.2), Glasgow (3.3), and Wrexham (3.1).

When compared to other natural forest types Oldham's urban forest compares well to both these and other urban forests which have been sampled using the i-Tree Eco methodology.

Foxdenton Park, Chadderton

Foxdenton Park, Chadderton

Pests and diseases

Pest and diseases are a serious threat to urban forests. The impact of climate change is changing and extending the range of pest and disease which are likely to affect the UK. This is exacerbated by the continued importation of trees, particularly large landscape trees, from across Europe and elsewhere and compounded by the ever increasing range of packaging materials used in international trade.

Severe outbreaks have occurred within living memory with Dutch Elm Disease killing approximately 30 million Elm trees in the UK.

The potential impact of pest and diseases may vary according to a wide variety of factors such as tree health, local tree management and individual young tree procurement policies. The weather also plays a significant role. In addition pest and diseases may 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 particular disease than a population which has a wider variety of tree species present. One of the prime objectives of any urban forestry management programme should be to facilitate resilience through population diversity.

Acute Oak Decline

There have been episodes of ‘oak decline’ documented for almost 100 years and it is regarded as a complex disorder whereby typically several damaging agents interact. The outcome results in high levels of mortality but trees can also recover. The most recent episodes of Acute Oak Decline have occurred predominantly in the South East and Midlands but is distribution has slowly intensified and spread to include Wales and East Anglia with occasional occurrences in the South West. The population of Oak in Oldham is approximately 15,000 trees and this represents over 3% of the total population.

Dutch Elm Disease

Acute Oak Decline

Asian Longhorn Beetle

Asian Longhorn Beetle is a native of South East Asia where it kills many broadleaved species. In America Asian Longhorn Beetle have established populations in Chicago and New York where damage to street trees can only be managed by high levels of felling, sanitation and quarantine. It is estimated by the United States Department of Agriculture and Forest Service that unless the spread of the beetle is contained up to 30% tree mortality could result.

To date the beetle has been found in the UK during the inspections of incoming packaging at several ports and a small population established in Kent in 2012 was located and removed by the Forestry Commission and the Food and Environment Research Agency.

The known host species include the following tree species:

Acer spp (Maples and Sycamore)
Aesculus (Horse Chestnut)
Albizia (Mimosa, silk tree)
Alnus spp (Alder)
Betula spp (Birch)
Carpinus spp (Hornbeam)
Cercidiphyllum japonicum (Katsura Tree)
Corylus spp (Hazel)
Fagus spp (Beech)
Fraxinus spp (Ash)
Koelreuteria paniculata
Platanus spp (Plane)
Populus spp (Poplar)
Prunus spp (cherry/plum)
Robinia psuedoacacia (false acacia/black locust)
Salix spp (willow)
Sophora spp (Pagoda tree)
Sorbus spp (Mountain ash/ rowan/whitebeam.)
Quercus palustris (American pin Oak)
Quercus rubra (North American red Oak)
Ulmus spp (Elm)

It is estimated that an infestation of Asian Longhorn Beetle in Oldham could impact on some 72,000 trees which represents 15.5% of the total tree population. Replacing these trees would cost £92 million.

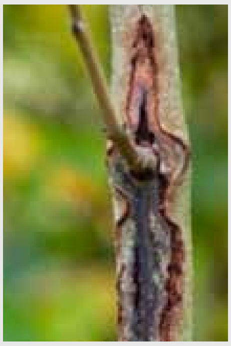
Asian Longhorn Beetle

Asian Longhorn Beetle damage

Chalara fraxinea

Ash dieback (Chalara fraxinea) is caused by the fungus Hymenoscyphus fraxineus. It induces vascular wilt, targeting common and narrow leaved Ash, which results in dieback and death. It is thought to have been introduced into Europe in 1992 and was first discovered in the UK on a nursery in 2012. Since being found in the UK the rate of infection has increased at a steady rate and has now been found in over 900 locations.

Although initially found in newly planted ash populations by the summer of 2014 infected trees were being found within established populations, including trees in urban areas and in the wider environment. Ash represents just over 12% of the tree population of Oldham with an estimated 57,606 trees.



Chalara fraxinea, Ash dieback

Emerald Ash Borer

There is no evidence to suggest that Emerald ash Borer is present in the UK. It is present in Russia and is moving West and South at a rate of 30–40km each year. A native of Asia it is thought that the beetle has been introduced to new countries on imported packaging material. It has caused the death of millions of Ash trees in the United States and once established has proved difficult to contain. The species which would be affected are the same as for Chalara. To replace these trees would cost more than £32 million.

Gypsy Moth

Gypsy Moth is a serious pest causing significant defoliation to oak trees, but also to species such as hornbeam, beech, chestnut, birch and poplar. It can cause death if serious defoliation occurs on a single tree. Breeding colonies persist in Aylesbury, Buckinghamshire and north east London. It has been present in the UK since 1995 with all known sites subject to an extensive pheromone based trapping programme managed by the Forestry Commission. In addition, the moth has urticating hairs which can cause severe allergic reactions to humans.
The potential host species named above account for some 45,795 trees within Oldham's tree population. This represents approximately 9.8% of the total tree population. To replace these trees would cost £9.3 million.

Chalara fraxinea, Ash dieback

Emerald Ash Borer

Plane Wilt

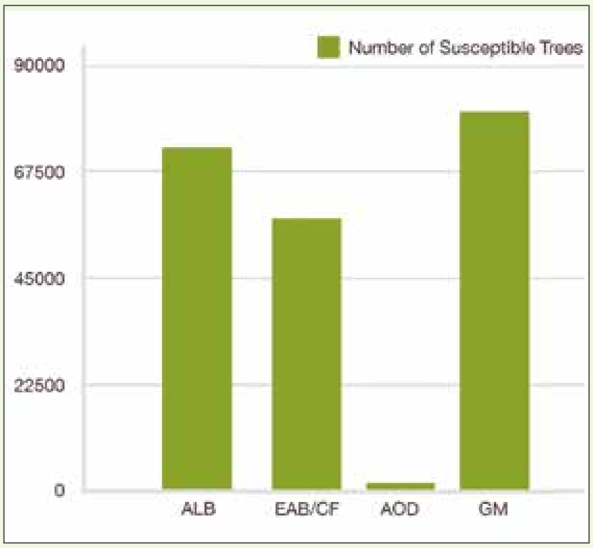
Ceratocystis fimbriata f.platani originates in the United States and causes canker stain on London plane and its parents P orientalis and P occidentalis. The pathogen was imported to a number of European ports during World War II on infected crating material and has spread rapidly through Switzerland and Italy. Its progress through France has been slower but reports indicate that it is moving northwards at a much faster rate than in previous decades.

The fungus causes severe wilting and mortality. It has yet to be identified as present in the UK. In Lyon in France the wilt is present and the only control measures available are felling and destruction and a reduction in the number of Plane trees planted. The fungus produces resilient long lived spores which survive in the soil but the main method of transfer is through human activity and the planting of plane imported from affected areas.

In Oldham there are only 671 plane trees and represents just 0.14% of the total tree population. To replace these trees would cost somewhere in the region of £1.6 million.

Plane Wilt

Figure 19: (below) Potential number of trees affected by pathogens and the cost of replacement

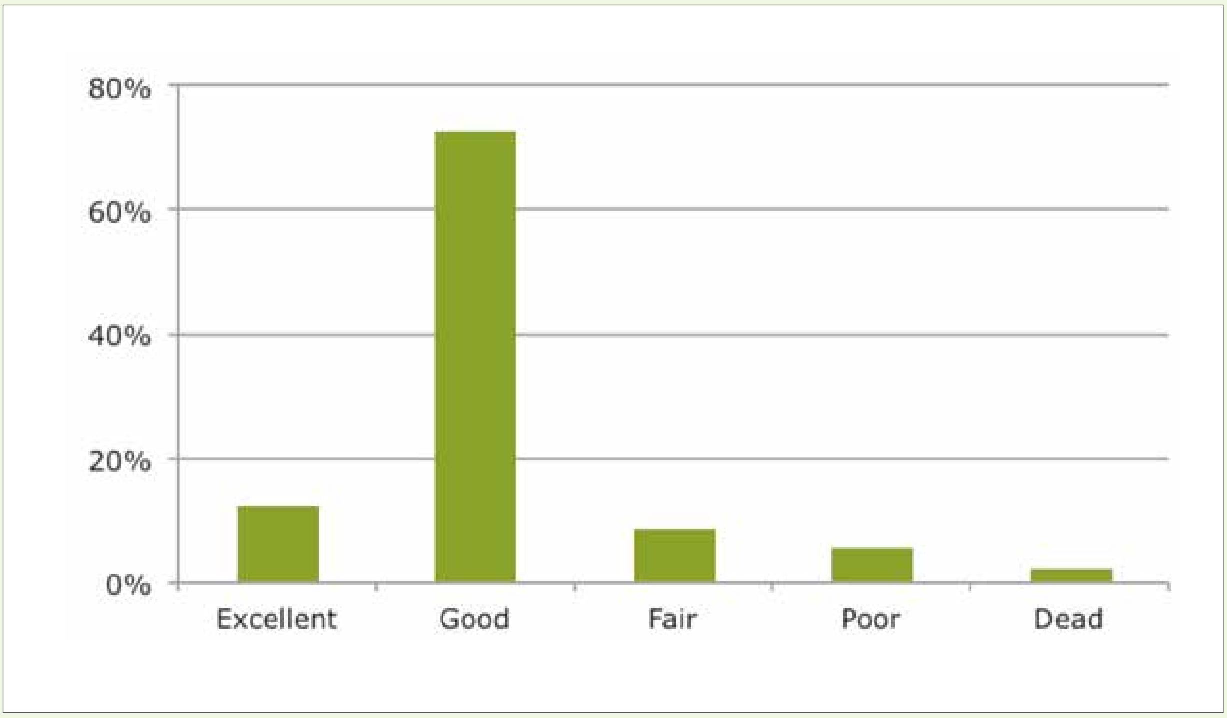


Gypsy Moth Caterpillar

Plane Wilt

One of the key factors in assessing the vulnerability of the resilience of a tree to pest and disease is the overall condition of that population. Tree condition was measured as part of this survey and Figure 20 (below) shows the overall health of the trees in Oldham.

Figure 20: Overall tree condition



Just under 84% of the trees assessed in Oldham were considered to be in to be in either excellent or good condition exhibiting less than 5% dieback. In FCHO urban this percentage fell slightly to 80% while rural Oldham the percentage was 81.5% and urban Oldham the percentage was 87%.

However, the percentage of trees considered in excellent condition varied between FCHO urban (53%) and urban Oldham (22%) with Rural Oldham only considered 3%. The percentage of trees considered dead or dying was 0% for FCHO urban with little difference between rural (2.6%) and urban (1.5%) Oldham.

Of the three most common species in FCHO urban, Cypress spp (Cupressuss spp) 60%, Sycamore (Acer psuedoplatanus) 100% and Maple spp (Acer spp) 100% were considered to be in excellent or good condition.

Of the three most common species in rural Oldham, Alder (Alnus glutinosa) 83%, Ash (Fraxinus excelsior) 100% and Larch (Larix kaempferi) 80% were considered to be in excellent or good condition. Of the three most common species in urban Oldham, Alder (Alnus glutinosa) 100%, Ash (Fraxinus excelsior) 83% and Norway Spruce (Picea abies) 100% were considered to be in excellent or good condition.

In rural and urban Oldham only Corsican Pine (Pinus corsica) 34%, Hawthorn (Crataegus spp) 37%, Bird Cherry (Prunus padus) 100% and Goat Willow (Salix caprea) 7% were considered to be in dead or dying condition. FCHO urban had no dead or dying trees.

Opposite: Dove Stone Reservoir, Greenfield

Conclusion

The results presented in this report help to demonstrate how Oldham's Tree resource is providing valuable benefits to all of its residents and visitors. For example, the filtration of Sulphur Dioxide alone is equivalent to the emissions of 41,000 cars every year.

Too often the main interactions between people and trees occur when they become a problem due to size, age or disease. Ash Dieback and Phytophthora diseases threaten around 30% of Oldham's tree resource and this could have a devastating effect on the provision of tree benefits and the landscape they occupy. By placing a value upon the benefits that these trees provide to the community, the management of the trees and future planting can be better justified, enabling more trees to be planted and the community to become more sustainable.

The detailed inventory within this report provides a firm basis on which to make future planning decisions. By increasing the volume of tree inventories in the wider areas and involving more community groups the degree of local ownership and appreciation of the urban forest will increase.

Understanding urban forest composition is the first step in the proactive management of this important resource. Now we can begin to strategically plan to improve and maintain our urban forest. Through targeted planting, maintaining, diversifying, monitoring, community engagement, training and a whole range of other activities we can ensure that Oldham's urban forest continues to provide benefits into the future.

Appendix I – i-Tree eco model and field measurements

i-Tree Eco is designed to use standardised field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects[27], including:

- Urban forest structure (species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percentage air quality improvement throughout a year.
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power sources.
- 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 long horned beetle, emerald ash borer, gypsy moth, and Chalara fraxinea.

In the field 0.04 hectare plots were randomly distributed, typically, all field data are collected during the growth season (with leaves present) to properly assess tree canopies. Within each plot, typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings[28].

During data collection, trees are identified to the most specific taxonomic classification possible. Trees that are not classified to the species level may be classified by genus (e.g. Ash) or species groups (e.g. hardwood). In this report, tree species, genera, or species groups are collectively referred to as tree species.

Tree characteristics

Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing. In the event that these data variables were not collected, they are estimated by the model.

An analysis of invasive species is not available for studies outside of the United States. For the United States, invasive species are identified using an invasive species list for the state in which the urban forest is located. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. In instances where a state did not have an invasive species list, a list was created based on the lists of the adjacent states. Tree species that are identified as invasive by the state invasive species list are cross-referenced with native range data. This helps eliminate species that are on the state invasive species list, but are native to the study area.

[27] Nowak and Crane 2000
[28] Nowak et al 2005; Nowak et al 2008

Air pollution removal

Pollution removal is calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter less than 2.5 microns. Particulate matter less than 10 microns (PM10) is another significant air pollutant. Given that i-Tree Eco analyses particulate matter less than 2.5 microns (PM2.5) which is a subset of PM10, PM10 has not been included in this analysis. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

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] that were adjusted depending on leaf phenology and leaf area.

Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[31]. 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[32]. Trees remove PM2.5 when particulate matter is deposited on leaf surfaces[33]. This deposited PM2.5 can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors. Generally, PM2.5 removal is positive with positive benefits. However, there are some cases when net removal is negative or resuspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees resuspend more particles than they remove. Resuspension can also lead to increased overall PM2.5 concentrations if the boundary layer conditions are lower during net resuspension periods than during net removal periods.

Since the pollution removal value is based on the change in pollution concentration, it is possible to have situations when trees remove PM2.5 but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common, but can happen.

For reports in the United States, default air pollution removal value is calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulphur dioxide, nitrogen dioxide, and particulate matter less than 2.5 microns using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP)[34]. The model uses a damage-function approach that is based on the local change in pollution concentration and population. National median externality costs were used to calculate the value of carbon monoxide removal[35]. For international reports, user-defined local pollution values are used. For international reports that do not have local values, estimates are based on either European median externality values (van Essen et al 2011) or BenMAP regression equations[36] that incorporate user-defined population estimates. Values are then converted to local currency with user-defined exchange rates.

For this analysis, pollution removal value is calculated based on the prices of £984 per tonne (carbon monoxide), £5,553 per tonne (ozone), £829 per tonne (nitrogen dioxide), £302 per tonne (sulphur dioxide), £192,844 per tonne (particulate matter less than 2.5 microns).

[29] Baldocchi 1988; Baldocchi et al 1987
[30] Bidwell and Fraser 1972; Lovett 1994
[31] Zinke 1967
[32] Hirabayashi et al 2011; Hirabayashi et al 2012; Hirabayashi 2011
[33] Nowak et al 2013
[34] Nowak et al 2014
[35] Murray et al 1994
[36] Nowak et al 2014

Carbon storage and sequestration

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

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[37]. To adjust for this difference, biomass results for open-grown urban trees were multiplied 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. Carbon sequestration is the removal of carbon dioxide from the air by plants. 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.

Carbon storage and carbon sequestration values are based on estimated or customised local carbon values. For international reports that do not have local values, estimates are based on the carbon value for the United States[38] and converted to local currency with user-defined exchange rates.

For this analysis, carbon storage and carbon sequestration values are calculated based on £63.80 per tonne.

Oxygen production

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition[39].
For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

Avoided runoff

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis.
The value of avoided runoff is based on estimated or user-defined local values. For international reports that do not have local values, the national average value for the United States is utilized and converted to local currency with user defined exchange rates. The U.S. value of avoided run-off is based on the U.S. Forest Service's Community Tree Guide Series[40].

Building energy use

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature[41] using distance and direction of trees from residential structures, tree height and tree condition data. To calculate the monetary value of energy savings, local or custom prices per MWH or MBTU are utilised. For this analysis, energy saving value is calculated based on the prices of £151.56 per MWH and £14.17 per MBTU.

Structural values

Structural value (Replacement Cost) is the value of a tree based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information[42]. Structural value may not be included for international projects if there is insufficient local data to complete the valuation procedures.

37 Nowak 1994
38 U.S. Environmental Protection Agency 2015, Interagency Working Group on Social Cost of Carbon 2015
39 Nowak et al 2007
40 McPherson et al 1999; 2000; 2001; 2002; 2003; 2004; 2006a; 2006b; 2006c; 2007; 2010; Peper et al 2009; 2010; Vargas et al 2007a; 2007b; 2008
41 McPherson and Simpson 1999
42 Nowak et al 2002a; 2002b

Potential pest impacts

The complete potential pest risk analysis is not available for studies outside of the United States. The number of trees at risk to the pests analysed is reported, though the list of pests is based on known insects and disease in the United States. For the U.S., potential pest risk is based on pest range maps and the known pest host species that are likely to experience mortality. Pest range maps for 2012 from the Forest Health Technology Enterprise Team (FHTET) (Forest Health Technology Enterprise Team 2014) were used to de-termine the proximity of each pest to the county in which the urban forest is located. For the county, it was established whether the insect/disease occurs within the county, is within 250 miles of the county edge, is between 250 and 750 miles away, or is greater than 750 miles away. FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively[43].

Relative tree effects

The relative value of tree benefits reported in Appendix II is calculated to show what carbon storage and sequestration, and air pollutant removal equate to in amounts of municipal carbon emissions, passenger automobile emissions, and house emissions.

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (Carbon Dioxide Information Analysis Center 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.
Light duty vehicle emission rates (g/mi) for CO, NOx, VOCs, PM10, SO2 for 2010[44], PM2.5 for 2011–2015 (California Air Resources Board 2013), and CO2 for 2011 (U.S. Environmental Protection Agency 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.
Household emissions are based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household in 2009 (Energy Information Administration 2013; Energy Information Administration 2014).

- CO2, SO2, and NOx power plant emission per KWh are from Leonardo Academy 2011. CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on Energy Information Administration 1994. PM10 emission per kWh from Layton 2004.
- CO2, NOx, SO2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Leonardo Academy 2011.
- CO2 emissions per Btu of wood from Energy Information Administration 2014.
- CO, NOx and SOx emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry 2005; Georgia Forestry Commission).

[43] Eastern Forest Environmental Threat Assessment Center; Worrall 2007
[44] Bureau of Transportation Statistics 2010; Heirigs et al 2004

Appendix II – Relative community benefits from trees

The urban forest in the Oldham i-Tree Project 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 car emissions, and average household emissions. See Appendix I for methodology.

Carbon storage is equivalent to:
- Amount of carbon emitted in Oldham i-Tree Project in 22 days
- Annual carbon (C) emissions from 51,900 cars
- Annual C emissions from 21,300 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 10 cars
- Annual carbon monoxide emissions from 28 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 5,090 cars
- Annual nitrogen dioxide emissions from 2,290 single-family houses

Sulphur dioxide removal is equivalent to:
- Annual sulphur dioxide emissions from 41,700 cars
- Annual sulphur dioxide emissions from 110 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Oldham i-Tree Project in 1.1 days
- Annual C emissions from 2,500 cars
- Annual C emissions from 1,000 single-family houses

View to Oldham Edge from Royton

Opposite: view of Diggle, Saddleworth

Appendix III – Species importance ranking list

Common Name	% Population	% Leaf Area	IV
Alder	24.00	12.70	36.70
Ash	12.30	11.60	23.90
Larch	7.10	16.80	23.90
Sycamore	4.60	16.50	21.10
Corsican Pine	6.50	6.30	12.70
Hawthorn	7.00	3.80	10.80
Black Poplar	2.70	3.10	5.90
Beech	2.60	2.90	5.50
Rowan	2.40	3.00	5.40
Birch	2.70	2.30	5.00
English Oak	3.40	1.60	5.00
Wild Cherry	2.80	2.20	5.00
Goat Willow	2.60	2.20	4.80
Spruce spp	1.60	2.70	4.30
Norway Spruce	2.70	1.30	4.10
Lime	1.50	0.80	2.30
White Willow	1.50	0.30	1.80
American Sycamore	0.30	1.20	1.50
Crack Willow	0.50	1.00	1.50
Holly	1.10	0.30	1.40
Leyland Cypress spp	0.80	0.40	1.20
Horse Chestnut	0.30	0.80	1.10
Hawthorn spp	0.60	0.40	1.00
Norway Maple	0.20	0.80	1.00
Sweet Chestnut	0.30	0.60	0.90
Japanese Cherry	0.50	0.40	0.90
Cypress spp	0.50	0.30	0.90
Swedish Whitebeam	0.50	0.40	0.80
Leyland Cypress	0.60	0.20	0.80
London Plane	0.10	0.60	0.70

Common Name	% Population	% Leaf Area	IV
Cherry Laurel	0.30	0.30	0.60
Beech spp	0.50	0.10	0.60
European Larch	0.30	0.20	0.50
Aspen	0.20	0.30	0.40
Maple spp	0.20	0.20	0.40
Wild Service Tree	0.20	0.20	0.40
Rhododendron spp	0.30	0.00	0.40
Palm spp	0.30	0.00	0.40
Whitebeam	0.10	0.20	0.30
Apple	0.20	0.10	0.30
Golden Monterey Cypress	0.20	0.10	0.30
Bird Cherry	0.20	0.10	0.30
Birch spp	0.20	0.10	0.30
Scots Pine	0.20	0.10	0.30
Holly spp	0.20	0.10	0.20
Eucalyptus	0.20	0.10	0.20
Hedge Maple	0.20	0.10	0.20
Elderberry	0.20	0.00	0.20
Blackthorn	0.20	0.00	0.20
Callery pear	0.20	0.00	0.20
Elderberry spp	0.20	0.00	0.20
Lawson Cypress	0.20	0.00	0.20
Flowering Ash	0.10	0.10	0.20
Japanese Maple	0.10	0.00	0.20
Bird Cherry spp	0.20	0.00	0.20
Cherry Plum	0.20	0.00	0.20
Pear	0.20	0.00	0.20
Western Red Cedar	0.20	0.00	0.20
Pear spp	0.10	0.00	0.10

Opposite: Alexandra Park, Oldham

Appendix IV – Full species list

Species	Number of Trees	Carbon Storage (nmt)	Gross Carbon Sequestration (nmt)	Leaf Area (ha)	Leaf Bio-mass (nmt)	Replacement Cost (£)
Wild Cherry	13087	2465.49	173.43	138.55	107.20	51037248.66
Alder	112024	7364.57	412.10	815.75	594.71	32369946.16
Sycamore	21467	13297.99	492.10	1060.81	741.83	25015461.23
Larch	33324	3760.32	176.50	1079.34	581.86	20477136.53
English Oak	15725	1705.24	80.10	104.03	69.26	13292062.69
Beech	11950	2681.21	93.62	188.32	94.24	11301508.73
Hawthorn	32700	4395.19	272.53	246.10	309.55	9869469.04
Crack Willow	2265	562.34	30.45	64.35	40.76	9097288.87
Ash	57270	8023.54	320.85	749.33	797.16	8262220.36
Corsican Pine	30145	4309.38	141.96	403.11	388.51	7417124.33
Black Poplar	12835	1246.61	60.02	201.61	145.39	5536377.55
Goat Willow	12332	3367.69	149.59	141.14	89.40	5313252.32
Rowan	11111	3938.89	126.26	194.90	154.68	4352184.73
Swedish Whitebeam	2181	361.77	27.54	24.03	19.07	2631470.20
White Willow	6795	1908.87	72.38	19.93	12.62	2306783.02
Japanese Cherry	2181	148.75	18.60	26.51	20.51	2193745.13
Elderberry spp	755	62.81	1.68	2.28	1.70	1615079.10
Leyland Cypress spp	3775	451.35	22.62	25.49	39.92	1434682.78
London Plane	671	427.55	17.43	38.38	17.63	1406668.02
Elderberry	755	68.73	8.36	2.87	2.15	1378867.20
Apple	1091	79.46	9.69	5.18	4.46	1218380.83
Blackthorn	755	21.22	1.74	2.69	2.08	1167481.29
Holly	5285	277.47	26.41	19.28	25.77	1163023.98
American Sycamore	1510	158.30	16.73	75.29	36.47	1106015.67
Spruce spp	7420	396.84	33.53	172.20	292.14	1101779.81
Lime	7000	185.24	16.06	48.52	22.57	966645.40
Cherry Laurel	1510	358.99	14.40	18.41	14.25	864122.12
Birch	12705	842.06	104.78	146.48	86.99	826372.44
Hawthorn spp	3020	559.58	33.10	24.59	8.84	762693.47
Horse Chestnut	1510	478.46	28.88	52.13	36.46	724588.30

Species	Number of Trees	Carbon Storage (nmt)	Gross Carbon Sequestration (nmt)	Leaf Area (ha)	Leaf Bio-mass (nmt)	Replacement Cost (£)
Norway Maple	1091	385.56	22.78	48.73	26.30	522138.94
Sweet Chestnut	1510	229.07	11.53	40.10	28.11	515897.01
Western Red Cedar	755	2.23	0.15	1.13	2.17	373575.40
Wild Service Tree	755	293.78	17.92	12.96	10.29	356125.20
Callery pear	755	15.26	3.26	2.50	1.87	302779.74
Palm spp	1510	3.61	0.14	2.29	3.83	300627.26
Beech spp	2265	32.86	3.91	5.59	2.80	285571.05
Eucalyptus	755	98.79	9.34	4.63	5.99	282561.78
Cypress spp	2433	268.25	12.27	22.31	34.94	227134.62
Leyland Cypress	2601	131.00	8.03	14.64	22.93	207081.31
Aspen	755	70.19	7.27	17.97	12.97	187833.35
Cherry Plum	755	17.46	3.82	1.17	0.71	185976.24
Norway Spruce	12835	288.12	19.99	85.01	141.68	161380.53
Birch spp	755	17.14	3.78	7.19	4.49	126633.54
Flowering Ash	336	89.90	4.15	7.37	5.25	118816.66
Rhododendron spp	1510	108.31	7.27	2.37	4.74	82546.31
Whitebeam	671	102.65	7.47	12.96	10.28	61284.38
Maple spp	1007	72.42	7.35	10.93	6.15	53793.51
Lawson Cypress	755	14.21	2.03	1.69	4.22	53793.51
Scots Pine	755	24.74	1.54	6.06	5.84	52402.58
Bird Cherry	755	46.88	0.55	8.33	6.44	47393.68
Hedge Maple	755	26.47	1.90	3.65	2.06	46937.20
Holly spp	755	64.09	7.16	5.57	7.44	45183.24
Pear	755	45.39	6.05	1.15	0.86	39036.35
Golden Monterey Cypress	755	31.85	3.09	8.43	13.19	37372.33
Bird Cherry spp	755	10.00	1.87	1.25	0.94	37372.33
European Larch	1510	80.24	5.01	12.12	6.54	30965.70
Pear spp	336	17.35	2.46	1.03	0.77	17459.30
Japanese Maple	671	13.14	2.63	2.57	1.45	13863.04
Study Area	466762	66506.89	3168.15	6443.26	5133.46	230983216.08

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Opposite: Dunwood Park, Shaw

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The Steering Group

Nik Anderson	Project Lead – Oldham Council
Matthew Moss, Ben Caine, Richard Orrell	Oldham Council
Chris Medrano, Julie Ashforth, Ric Dawson	First Choice Homes Oldham
Tony Hothersall, Beth Kelsall	Manchester City of Trees

The Authors

James Watson	Treeconomics
Joanna Bayley	Treeconomics
Keith Sacre	Treeconomics
Kenton Rogers	Treeconomics

The Volunteers

Beth Kelsall
Bob Kenworthy
Derek Valentine
Jim Williams
Karen Williams
Kimberley Seddon
Lee Adair
Richard Wainwright
Charles Hicklin
Usman Shabir

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www.oldham.gov.uk

Oldham Council