Research Report

The benefits to people of trees outside woods

WOODLAND TRUST

Contents

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Summary

- Trees outside woods (TOWs) are all trees that do not fall within the definition of a woodland, and consists of patches of trees <0.5 ha, trees along linear features, and lone trees. A recent inventory has determined that there are 742,000 ha of TOWs in Britain, corresponding to 3.2% of total land cover, and representing 19% of all tree cover.
- TOWs provide a range of benefits to society, known as ecosystem services, and which can be categorised as regulating, cultural and provisioning services. This report provides a review of these benefits, including their monetary value, and also the disbenefits provided by TOWs.
- Trees are very effective at mitigating the effects of air pollution, primarily by intercepting airborne particulate matter, but also by absorbing ozone, SO_2, NO_x and ammonia. However, there are major differences in the ability of different species to intercept pollution. The location of trees relative to pollution sources also determines how effective they are at removing pollutants, with trees close to sources being the most effective.
- Trees, especially large ones, are able to store significant amounts of carbon. The two factors that most influence carbon uptake are growth rates and wood density, with considerable inter-specific variation. Total life cycle carbon sequestration in urban and roadside locations may be maximised by selecting tree species with high wood densities rather than growth rates.
- Trees have a moderating effect on local climate, although tree location in relation to buildings can have a major influence on impact. Densely planted tree belts can also reduce noise levels, but the effects are modest, with reductions of 2-4 dB typically recorded.
- TOWs can provide hydrological benefits in the form of avoided runoff and flood alleviation, and water quality enhancement. Evidence indicates that tree planting can significantly reduce peak flood flows, flow volumes and time to peak at small scales, but that the effect diminishes as the scale of the catchment increases. Belts of riparian woodland adjacent to agricultural fields are effective at removing almost all of the nitrate and phosphate pollutants in surface runoff.
- Multiple benefits arise from incorporating trees with agriculture. Tree shelterbelts can enhance the yield of crops due to reduced wind erosion, improved microclimate, increased soil moisture, and reduced crop damage. Trees and shelterbelts are also important for sheltering livestock from exposure to both heat and cold winds. TOWs provide significant floral resources and nesting opportunities for pollinators, which then pollinate crops and subsequently increase yield. Woody habitats and shelterbelts in agricultural landscapes can suppress invertebrate pests through the enhancement of natural enemy populations.
- In terms of cultural services, scattered trees and other types of TOWs are a fundamental part of the cultural landscape of the UK, providing character and local distinctiveness to many rural areas. Within urban areas, people show a generally favourable attitude towards street trees, with the most highly rated benefit being visual attractiveness.
- There is strong and growing evidence linking exposure to trees with enhancements in both physical and mental health and wellbeing. Short-term physical benefits of trees have been measured simply through sitting in a room with tree views. Other benefits include: speeding recovery from surgery and illness, enhancing attention and cognitive function, improving mental health and wellbeing, improving pregnancy and birth outcomes, reducing mortality rates (especially related to cardiovascular and respiratory diseases), and encouraging physical activity. In addition, evidence suggests that in urban areas the presence of trees can be used to deter crime and anti-social behaviour. Roadside trees also have an impact on road safety, reducing the frequency and severity of crashes, reducing traffic speed and enhancing pedestrian safety.
- Traditionally, TOWs have been important sources of timber, fuel, fodder, fruit, nuts and berries. Although these uses are limited now, there is growing interest and potential for using road verges to produce short rotation willow and poplar coppice for biofuel.

"Trees outside woods can provide hydrological benefits in the form of avoided runoff and flood alleviation, and water quality enhancement"

- TOWs can also provide disservices, ranging from relatively minor nuisances such as complaints about unsightly unmanaged trees and trees creating a sticky residue on parked cars, to potentially serious health effects. Roadside urban trees have been shown to increase pollutant concentrations locally in certain situations, by trapping pollutants at street level. Trees can emit volatile organic compounds (VOCs) and pollen from trees is a significant allergen. Tree roots can also break up pavements and roads, indirectly cause building subsidence, and trees can cause unwanted shading. High density tree and shrub planting can be perceived as unsafe.
- Disbenefits often occur as a result of the wrong type of tree being planted in the wrong place. Likewise, benefits can be maximised by planting the right tree in the right place. When deciding on which trees to plant where for effective ecosystem service delivery, a review by O'Sullivan et al. (2017) of trees in road verges provides a useful assessment of the key ecosystem services provided by different tree species.
- Using economic valuation methods, it is possible to assess the costs and benefits of TOWs in monetary terms. A range of possible valuation methods is briefly reviewed and monetary values for several ecosystem services are collated from UK and international studies. When all the trees in an urban area are combined, the overall value is considerable, with annual values ranging from £27.8M for Bridgend up to £1,837M for London.
- Taking planting and maintenance costs into account, urban trees deliver considerably more benefits than they cost. It is likely that overall annual costs including both planting and maintenance will be around £25 per tree in the UK, with £81 of benefits delivered. This gives a net benefit of approximately £56 per tree per year and a cost benefit ratio of 1:3.2.
- TOWs provide a wide range of benefits to society. However, these are not always recognised and valued, whereas the costs of damage are widely reported, meaning that trees can be viewed as a liability rather than an asset. Understanding the full range of benefits and disbenefits provided by TOWs and how these vary with location and tree characteristics is thus a key step in achieving more sustainable management of these assets.
- Various policy and management recommendations are provided. These include routinely considering the multiple benefits provided by trees; placing greater emphasis on planting the right tree species in the right location; always replanting felled trees; and further research into, amongst others, the value of TOWs and the potential impact of threats such as ash dieback.

Introduction

Trees outside woods (TOWs) provide a wide range of benefits to society. However, these are often not recognised or valued, which can lead to poor management decisions. This report sets out to address that issue by reviewing the evidence of the benefits, the disbenefits, and the economic value of TOWs. This first section of the report defines the context of this review, provides a framework for assessment, and briefly outlines the content and structure of the rest of the report.

1.1 What are trees outside woods?

According to the National Forest Inventory, woodland is defined as any area of land covered by trees with an established canopy that is greater than 0.5 hectare in extent. The area must have, or have the potential to achieve, at least 20% crown cover and with a minimum width of 20m (Forest Research 2016). Trees outside woods (TOWs) can most simply be defined as all other tree resources that do not fit the definition of woodland. This will include small woods (0.1-0.5 ha), groups of trees (<0.1 ha), both of which can be categorised as linear or non-linear, and lone trees (Forest Research 2017). TOWs tend to be located in three main areas of the landscape:

- Trees in the agricultural landscape
- Trees in urban areas
- Trees alongside transport corridors

The extent of TOWs in the landscape has been published as part of the National Forest Inventory, with results presented in the report Tree cover outside woodland in Great Britain (Forest Research 2017). This has revealed that there are 742,000 ha of TOWs in Britain, consisting of 390,000 ha of small woods, 255,000 ha of groups of trees, and 97,000 ha of lone trees (the latter comprising just over 30M individual trees). This corresponds to 3.2% of the land cover of Britain and represents 19% of all tree cover. In urban areas TOWs make up 11% of land cover and overall tree cover (TOWS and woodland combined) is 16.5%, whilst in rural areas TOWs make up 3% of land cover and overall tree cover is 16.7% (Forest Research 2017). Thus TOWs are particularly significant in urban areas, and make up 67% of overall tree cover.

The National Forest Inventory provides the most accurate and up-to-date picture of the extent of TOWs recorded. Previous studies have tended to be less accurate at identifying smaller features or have focussed on specific areas. A major survey of 147 English towns and cities in 2005 revealed that the overall mean tree canopy cover, as calculated from aerial photographs, was 8.2%, with an average density of 58.4 trees per hectare (Britt and Johnston 2008). This survey excluded urban woodlands so was a good reflection of TOWs in urban areas.

Higher resolution plot-based surveys conducted in 8 urban areas over the last few years (see Section 2 for more details) revealed a mean canopy cover of 15.5%, with an average of 91 trees per hectare. However, these studies assessed all trees, so included areas of urban woodland alongside TOWs, and some of these studies also extended into nearby rural areas. Meanwhile, in London there are estimated to be approximately half a million street trees (London Assembly 2011) and 8.4 million trees in total (Rogers et al. 2015).

A large number of Ash trees are found outside of woodlands.

1.2 The natural capital and ecosystem services framework

The natural environment underpins our wellbeing and economic prosperity, providing multiple benefits to society, yet is consistently undervalued in decision-making. Natural capital is the stock of natural assets, including habitats, water, soil, biodiversity and trees that produce a wide range of benefits for people. These benefits are known as ecosystem services and include, for example, food, timber production, regulation of flooding and climate, pollination of crops, and cultural benefits such as aesthetic value and recreational opportunities (Fig. 1). Performing an assessment of ecosystem services is a way of recognising the natural environment for the multiple benefits that it provides.

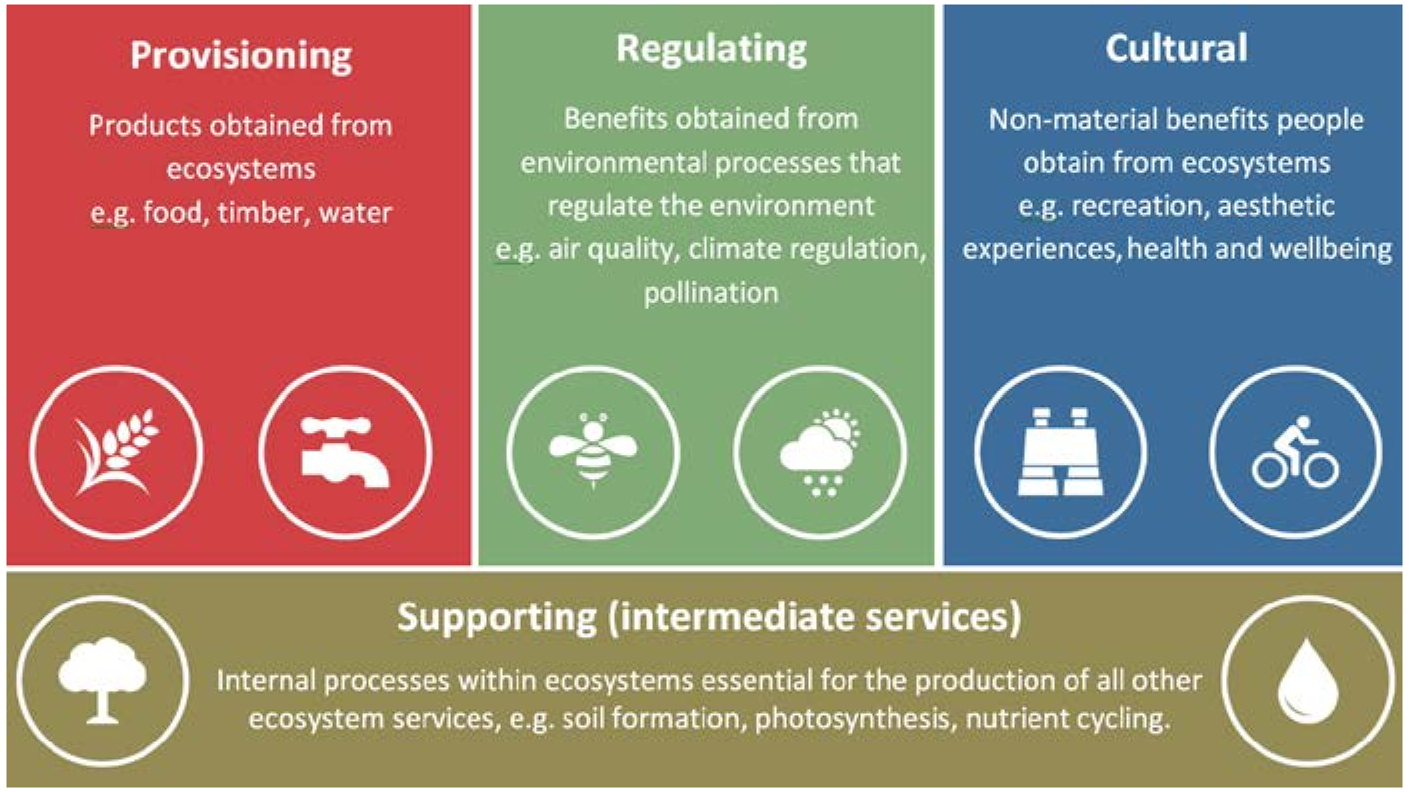


Figure 1: Key types of ecosystem services (based on MEA 2005)

Provisioning, regulating and cultural services are often referred to as 'final services', as they provide goods and services from which people directly benefit. Supporting services, on the other hand, are nowadays referred to as 'intermediate services' or ecosystem processes and are not usually assessed in ecosystem services assessments. Many of these processes are essential in driving the provisioning, regulating and cultural services, but they are not final services, and including them would also lead to double-counting the benefits received.

Adopting the natural capital and ecosystem services approach is a key policy objective of the UK Government (and worldwide) and central to Defra's new 25-year plan. Much work is progressing on how to deliver the approach on the ground and how to use it to inform and influence management and decision-making. One of the most important steps is to recognise and quantify ecosystem service delivery (the physical flow of services derived from natural capital). It is also possible to provide a monetary valuation (monetary flow) of a number of ecosystem services. Even greater insight can be gained by taking a spatial perspective on the variation in ecosystem service supply and demand across a study area using a Geographic Information System (GIS). Maps are able to highlight hotspots and cold spots of ecosystem service delivery, highlight important spatial patterns that provide much additional detail, and are inherently more user friendly than non-spatial approaches.

1.3 Review structure

In this report, we provide a review of the many benefits (and the disbenefits) provided by trees outside woods (TOWs). We do not, however, include the ecological benefits as these are reviewed in a separate report (Feber 2016). Note also, that due to the breadth of the subject, we do not attempt to be comprehensive and review all published material related to each topic, as each sub-heading in this report could be the subject of its own review. Instead we attempt to include a broad range of topics and provide key references for each. We adopt an ecosystem services framework in which to report the benefits and also consider the monetary valuation of these ecosystem services.

The report begins by examining the ecosystem service benefits provided by TOWs – the key regulating, cultural and provisioning services of benefit to people (Section 2). We then examine the disservices – the negative impacts of TOWs on people (Section 3), before briefly mentioning the importance of planting the right tree in the right location (Section 4). We then review monetary valuations of TOWs (Section 5), before ending with conclusions and recommendations (Section 6).

2. The ecosystem service benefits provided by TOWs

Trees outside woods (TOWs) provide a range of benefits to society. These are reviewed below and summarised in Table 1. As well as reviewing evidence from the scientific and grey literature, we have also examined a number of recent detailed assessments of the benefits of trees in case study locations across the UK. Assessments have been carried out in eight urban areas: Torbay (Rogers et al. 2012), Edinburgh (Hutchings et al. 2012), Wrexham (Rumble et al. 2015a), Glasgow (Rumble et al. 2015b), Sid Valley (Rogers 2015), London (Rogers et al. 2015), Bridgend (Doick et al. 2016a), and the Tawe catchment (Doick et al. 2016b). The focus of these studies is very much on built-up areas, although some of these studies also include a substantial element of rural habitat, especially the Sid Valley study and the Tawe catchment (predominantly Swansea, but also including extensive upstream rural areas). In addition, one assessment has been performed on an area of the road network known as Highways Agency Area 1 (Rogers and Evans 2015). Area 1 consists of the A30 and A38 trunk roads to the west of Junction 31 on the M5 near Exeter in Devon and Cornwall, and in total contains 289km of trunk road in predominantly rural settings. Data from these studies has been compiled in Table 2 to show characteristics of tree cover along with the physical flow of benefits that arise in terms of air pollution removal, carbon storage and sequestration, and avoided runoff. These results are discussed in the relevant sections below.

2.1 Regulating services

2.1.1 Air quality amelioration

According to the World Health Organisation, air pollution is the greatest environmental health risk in Western Europe and globally. In the UK alone it is estimated to have an effect equivalent to 29,000 deaths each year and is expected to reduce the life expectancy of everyone in the UK by 6 months on average, at a cost of around £16 billion per year (Defra 2015a). Air pollution also contributes to climate change, reduces crop yields, and damages biodiversity.

Vegetation can be effective at mitigating the effects of air pollution, primarily by intercepting airborne particulates, especially PM_{10} (particulate matter 10 micrometres or less in diameter), but also by absorbing ozone, SO_2 and NO_x. Trees are much more effective than grass or low-lying vegetation, although effectiveness varies greatly depending on the species. It has been reported that trees with a large leaf surface area can remove 60 to 70 times more gaseous pollutants a year than small ones (Salmond et al. 2016). Similarly, in a study of 22 trees and 25 shrubs in Norway and Poland, Sæbø et al. (2012) reported that there was a 10- to 15-fold difference in particulate matter accumulation on leaves. *Pinus sylvestris* (Scots pine) and *Betula pendula* (silver birch) were the most efficient species in capturing PM, whilst important traits for PM accumulation were leaf properties such as hair and wax cover (Sæbø et al. 2012). Overall, coniferous trees are considered to be more effective than broadleaved trees at ameliorating air pollution (Freer-Smith et al., 2005) due to the higher surface area of needles and because the needles are not shed during the winter. However, they are more sensitive to air pollution and will not survive in the most polluted sites (Forestry Research, undated).

A large number of Ash trees are found outside of woodlands.

Table 1: The ecosystem service benefits provided by trees outside woods and some of the economic implications of these services.

Tree ecosystem services	
Regulating services	
Absorbing air pollution – particulate matter (PM), NO_x, SO_2, ozone, carbon monoxide, ammonia	Reducing energy use
Removing dust and odour	Reducing glare
Producing oxygen	Reducing rate and volume of storm water runoff
Sequestering and storing carbon – directly and in soil	Reducing flood risk
Providing shade	Recharging ground water
Reducing summer air temperatures and the urban heat island effect	Enhancing water quality
Providing shelter from wind	Reducing soil erosion
	Attenuating noise
	Screening unattractive or noisy places
Benefits to agriculture	
Providing shelter for crops and livestock	Providing stock enclosure
Providing shade for livestock	Reducing spread of disease – especially bovine TB
Supporting pollinators and enhancing crop yields	Providing habitat and cover for game birds
Enhancing pest control	Enhancing output for free-range poultry farms
Cultural services	
Providing and enhancing landscape character	Enhancing community cohesion
Contributing to sense of place and identity	Reducing aggression, violence and crime rates
Part of cultural heritage	Increasing security
Enhancing aesthetics	Enhancing driver and pedestrian safety
Benefiting physical health – reducing blood pressure, stress, asthma	Reducing road traffic speeds
Speeding recovery from surgery and illness	Enhancing privacy
Enhancing attention and cognitive function	Bringing people closer to nature
Improving mental health and wellbeing	Providing setting for outdoor learning
Improving pregnancy and birth outcomes	Improving educational outcomes through improvements in concentration and performance and reduced time off for illness
Reducing mortality rates – especially related to cardiovascular and respiratory diseases	Enhancing quality of life
Encouraging physical activity	Providing spiritual value and meaning
Provisioning services	
Source of timber, fuel, fodder, fruit, nuts and berries	Source of biofuels
Economic benefits	
Increasing land and property prices	Reducing heating and cooling costs
Reducing 'time on market' for selling property	Increasing property taxes
Attracting business and customers	Enhancing rental income
Reducing health care costs	Increasing tourism revenues
Reducing expenditure on air pollution removal	Reducing screening costs especially next to main roads
Reducing expenditure on storm water infrastructure	Reducing agricultural costs and enhancing farmer income
Reducing expenditure on flood defences	Providing potential for future carbon offsetting trade
Saving investment in new power supplies	

Table 2: Tree cover characteristics and the physical flow of ecosystem services provided by trees from 8 urban and 1 rural roadside locations. Figures show the total amount of service provided across the study area, the mean per tree and the mean per square metre of canopy, for air pollution removal, carbon storage and sequestration, and avoided runoff.

	Torbay	Edinburgh	Wrexham	Glasgow	Sid Valley	London	Bridgend	Tawe catchment	Highways Agency 1
Year of study	2010	2011	2013	2013	2014	2014	2014	2014	2014
Forest cover (ha)	11.8%	17%	17%	15%	23.2%	14%	12%	16%	34.9%
Number of trees	818,000	638,000	364,000	2,000,000	405,000	8,421,000	439,000	530,000	303,000
Density (trees / ha)	105	56	95	113	87	53	99	76	312
Air pollution removal:									
Total (tonnes)	50	100	60	283	57	2241	61	136	29
g per tree	61	157	165	142	141	266	139	257	96
g per m^2 of canopy	6.6	5.1	9.2	10.7	5.3	10.0	11.4	12.2	8.5
Carbon storage:									
Total (tonnes)	98,100	145,611	65,800	183,000	80,200	2,367,000	53,500	102,000	22,200
Kg C/tree	120	228	181	92	198	281	122	192	73
Kg C/m^2	13.0	7.5	10.1	6.9	7.4	10.6	10.0	9.1	6.5
Net carbon sequestration:									
Total (t/year)	3,320	4,721	1,329	8,000	2,640	65,534	2,079	3,000	1,980
Kg C/tree/year	4.1	7.4	3.7	4.0	6.5	7.8	4.7	5.7	6.5
Kg C/m^2/year	0.44	0.24	0.20	0.30	0.24	0.29	0.39	0.27	0.58
Avoided runoff:									
Total (m^3)	-	-	278,000	812,000	215,000	3,414,000	123,727	252,200	75,753
Litres per tree	-	-	764	406	531	405	282	476	250
Litres per m^2	-	-	42.7	30.7	19.9	15.3	23.2	22.5	22.3

Data calculated from the following sources: Torbay (Rogers et al. 2012), Edinburgh (Hutchings et al. 2012), Wrexham (Rumble et al. 2015a), Glasgow (Rumble et al. 2015b), Sid Valley (Rogers 2015), London (Rogers et al. 2015), Bridgend (Doick et al. 2016a), Tawe catchment (Doick et al. 2016b), Highways Agency Area 1 (Rogers and Evans 2015).

“Roadside trees are effective at capturing pollutants in rural areas as well as in urban centres”

In terms of effect size, a single tree can reduce PM concentration by 15-20% (Mitchell and Maher 2009, Bealey et al., 2007). However, most studies at city scale show a fairly small overall reduction in pollution concentration of less than 5% resulting from urban vegetation. For example, Tallis et al. (2011) modelled PM10 concentrations across London and reported a 0.7-1.4% reduction due to vegetation, although they suggested that this could be increased by targeting the areas with the worst air quality and by planting the most effective species.

Although the average percent air quality improvement due to trees is relatively low, the improvement is for multiple pollutants and the actual magnitude of pollution removal can be significant. For example, a study of air pollution removal by urban trees across 55 cities in the USA showed that total pollution removal varied from 22 tonnes per year to 11,100 t/year (Nowak et al. 2006). Pollution removal values per unit of canopy cover varied from 6.2 to 23.1 g/m$_2$/year with a median of 10.8 g/m$_2$/year. Equivalent figures can be calculated for the UK based on studies in eight towns and cities (see Table 2). Pollution removal values ranged from 5.1 to 12.2 g/m$_2$/year, with a median of 9.6 g/m$_2$/year (or a median of 149 g/tree/year), with absolute values ranging from 50 t/year in Torbay to 2,241 t/year in London. The monetary value of these levels of pollution removal can be very high (see Section 5).

The location of trees relative to pollution sources determines how effective they are at removing pollutants, with trees close to sources being the most effective. Traffic on major roads is one of the most significant sources of air pollution in the UK, hence roadside trees can be particularly beneficial. One study in Lancaster found that temporarily installing a line of young silver birch trees outside a row of terraced houses in a street with high traffic volume led to >50% reductions in measured PM levels inside those houses (Maher et al. 2013). The authors suggested that rather than increasing total urban tree cover, single roadside tree lines of a selected, highly effective, PM-tolerant species appeared to be optimal for PM removal.

Roadside trees are effective at capturing pollutants in rural areas as well as in urban centres. Although there is much less data available from rural roadsides, based on a study of two major trunk roads in south-west England, it is possible to calculate that the roadside trees are removing pollution at a rate of 8.5 g/m$_2$/year or 96 g/tree/year, which is similar to the urban figures above.

Trees are also able to absorb ammonia (NH_3). Agriculture was responsible for 81% of ammonia emissions in the UK in 2015, with the majority of this derived from livestock (Defra 2016). Across all livestock types, the greatest emissions are from livestock housing and from land after manure spreading (Defra 2002). Once emitted, ammonia is usually deposited as ammonium, which is having a profound negative impact on semi-natural habitats in the UK, especially habitats that are naturally low in nitrogen such as heathlands, upland habitats and acid grasslands. Indeed, deposition of ammonium exceeds critical loads for nitrogen enrichment at over 64% of the heathland and moorland in the UK (Defra 2002). However, research has shown that a screen of trees can be effective at removing large quantities of ammonia. Studies in the USA showed that a buffer of 3 rows of trees (c.10m wide) placed close to the extractor outlets of a number of poultry houses reduced ammonia by 53% (Frazer 2008). Dust and odour are also a significant concern around poultry houses as these can impact on the health of both livestock and farm workers, but the same tree belts were able to reduce dust by 56% and odour by 18% (Frazer 2008). It was recommended that the first row of trees should be deciduous as these drop the dust and feathers that accumulate on the leaves each autumn which can kill coniferous trees over time.

Sutton et al. (2002) and Dragosits et al. (2006) took a landscape approach to determine the best strategy to protect sensitive habitats from ammonia deposition, especially given that ammonia levels can vary substantially across small areas of a farm. They found that planting a belt of trees was just as effective as a considerably wider buffer of low emission agriculture. They also modelled the difference between planting the trees either around key sources of ammonia (animal houses) or around key sinks (semi-natural habitats that required protection) and found that planting around the semi-natural habitats was most effective at reducing ammonia levels within those habitats (Dragosits et al. 2006). This was likely to occur as these were able to capture ammonia from all sources rather than just from livestock housing. The impact on semi-natural habitats depended on the size of the site, with small sites more vulnerable to ammonia deposition due to the higher

Roadside trees are effective at capturing pollutants in rural as well as urban areas

proportion of edge habitat exposed to sources, but also benefiting to a greater degree from tree belts. A 25m tree belt could potentially reduce deposition by between 3.4 and 15.5% depending upon the characteristics of the site (Dragosits et al. 2006).

2.1.2 Carbon storage and sequestration

Carbon storage and sequestration is seen as increasingly important as we move towards a low-carbon future. The importance of managing land and vegetation as a carbon store has been recognised by the UK government and has a major role to play in national carbon accounting. Changing land use and vegetation from one type to another can lead to major changes in carbon storage. In addition, carbon sequestration rates (annual uptake of carbon) vary greatly between different types of vegetation. Carbon is increasingly being given a monetary value and forms the basis of Payments for Ecosystem Services (PES) schemes such as the UK Woodland Carbon Code.

Trees, especially large ones, are able to store significant amounts of carbon. In the USA, whole tree carbon storage densities in urban areas were reported to average 7.69 Kg C/m^2 of tree cover (Nowak et al. 2013). Equivalent figures for the UK based on studies in eight towns and cities (see Table 2) gave a mean of 9.33 Kg C/m^2, although Davies et al. (2011) recorded mean carbon storage of 28.86 Kg C/m^2 in trees on publicly owned or managed sites in Leicester. Carbon sequestration rates are also significant, with net uptake of 0.21 Kg C/m^2 of tree cover per year in urban areas in the USA (Nowak et al. 2013) and the equivalent figure from the UK of 0.30 Kg C/m^2/year (Table 1). This works out at a mean of 1.65 tCO^2e/ha/year for the eight areas.

The two factors that most influence carbon uptake are growth rates and wood density, with considerable inter-specific variation. Total life cycle carbon sequestration in urban and roadside locations may be maximised by selecting tree species with high wood densities rather than growth rates as this would likely reduce management requirements associated with large trees that can create a safety risk or cause infrastructure damage (Mullaney et al. 2015). In addition, reducing management of urban and roadside trees and allowing them to reach maximal growth potential will increase their contribution to carbon sequestration.

As well as sequestering and storing carbon within the trees themselves, planting trees will also lead to a gradual accumulation of carbon in the soil. Soil carbon stock is considerably higher under broadleaved woodland than farmland or amenity grassland (Cantarello et al. 2011). Planting trees will lead to a gradual accumulation of carbon, over 50-100 years, although levels under individual trees or small groups of trees are unlikely to reach that found in woodlands.

A further advantage of planting TOWs to sequester carbon is that they can fit into the existing landscape. It has often been suggested that the UK should plant large areas of new woodlands to help mitigate against climate change, but one criticism of this policy is that this would take up large quantities of land, potentially leading to conflicts with other land uses and issues around food security. However, if trees are planted on roadsides, field margins and in urban areas, it is possible to go a large way to meeting carbon mitigation targets, without the need for significant land use change and will deliver additional benefits as described in this review (Falloon et al 2004).

2.1.3 Microclimate influence and energy saving

Land use can have a significant effect on local temperatures. Urban areas tend to be warmer than surrounding rural land due to a process known as the 'urban heat island' effect. This is caused by urban hard surfaces absorbing more heat, which is then released back into the environment, coupled with energy released by human activity such as lighting, heating, vehicles and industry. Air temperatures up to 9°C hotter have been reported in urban areas in the UK compared to nearby countryside. This is significant as heat-related stress accounts for around 1100 premature deaths per year in the UK, with significant increases in exceptionally hot years (Doick and Hutchings 2013). Climate change impacts are predicted to make the overheating of urban areas and urban buildings a major environmental, health and economic issue over the coming years.

"Trees can be important in reducing energy use through their functions as both shelter and shading"

Natural vegetation, especially trees and woodland, has a moderating effect on local climate, making nearby areas cooler in summer. This occurs due to three processes: direct shading reduces both heat and UV radiation, evapotranspiration causes cooling, and vegetation does not absorb as much heat as built surfaces. Green spaces in urban areas such as parks can be particularly effective at reducing the urban heat island effect, but individual trees can also have some effect. The temperature beneath canopies of individual trees is usually lower than that of the surrounding air, although most of the quantitative evidence relates to larger green spaces and neighbourhoods with differing levels of tree cover rather than individual trees (reviewed in Doick and Hutchings 2013). However, in a study from Manchester, shade from street trees reduced surface temperatures by an average of 12°C and concrete surfaces shaded permanently by a bank of trees were cooled by up to 20°C in the summer (Armson et al. 2013), although these had no effect on air temperatures. The cooling effect of trees extends out into the surrounding area and can be detected up to 80m away (reported in Bowler et al. 2010).

There is evidence that different tree species vary in their ability to reduce local temperatures, possibly due to factors such as tree size and canopy characteristics (Bowler et al. 2010, Doick and Hutchings 2013). In addition the location of the tree relative to buildings is important in determining the overall effect. For example, a tree planted to the west of a building will provide good cooling of the building in the summer and have limited impact in the winter, whereas a tree planted to the south will have little effect in the summer but will cause unwanted cooling in winter. Low winter temperatures are a health risk in temperate Europe and thus deciduous trees should be selected to restrict cooling to the summer (McPherson et al. 1988). See Doick and Hutchings (2013) for a much fuller review of these issues.

Trees can be important in reducing energy use through their functions as both shelter and shading. In windy countries such as the UK, considerable heat loss occurs through wind chill, and trees are used in many areas to provide shelter. In northern US and Canadian farms shelter belts have been shown to cut the average energy use by 10% to 30% (Dewalle and Heisler 1988). Similarly, Heisler (1986) reported that windbreaks can reduce the energy requirements for heating houses by between 10 and 25%. In the summer, trees providing shade can reduce cooling costs in buildings, with large energy saving reported from the USA (Akbari et al. 1997). As summer temperatures are predicted to rise in the UK over the coming decades, requirements for cooling in summer are likely to become increasingly important.

2.1.4 Avoided runoff and flood alleviation

Trees outside woods (TOWs) can provide hydrological benefits in the form of avoided runoff and flood alleviation, as well as water quality enhancement (discussed in Section 2.1.5). There are a number of mechanisms by which trees can help alleviate flooding (Nisbet et al. 2011, Mullaney et al. 2015): direct interception, promoting higher infiltration rates into the soil, through greater water use, and through greater hydraulic roughness. Leaves and branches intercept, absorb and temporarily store water before it evaporates from tree surfaces or gradually infiltrates into the soil. Mature deciduous trees can intercept between 1.89 and 2.65 m^3 of water per year, while evergreen trees including pines can intercept even

Trees outside woods can help alleviate flooding

more (cited in Mullaney et al. 2015). Xiao and McPherson (2016) measured the surface water storage capacity for 20 different tree species and found that there was a threefold difference among tree species. However, for most rainfall intensities, an event exceeding 30 minutes invariably exceeded the storage capacity of even large trees.

In addition to direct interception, trees can also improve infiltration of rainfall into the ground. As well as reducing the rate at which rainfall reaches the ground, roots take up water and increase the soil's water holding capacity by creating additional soil pores. In urban areas, tree pits allow for much greater infiltration rates than sealed surfaces. In addition, in severely compacted soils, tree roots have been shown to improve infiltration by 153% (Bartens et al. 2008). Species with high water use requirements will further reduce flood risk, although they will be less drought resistant.

Based on five separate studies using a variety of different methods, the average volume of water removed by urban trees was 6.24 m^3/tree/year (individual studies cited in Mullaney et al. 2015). In contrast, studies in 6 UK areas based on the iTree methodology have reported a mean volume removed of 0.48 m^3/tree/year (Table 2), more than an order of magnitude lower. However, this will still lead to a significant reduction in pressure on drainage systems in urban areas. In rural areas too, TOWs can reduce flood risk by absorbing run-off from roads and agricultural areas. In addition, saturated hydraulic conductivity and infiltration rates have been shown to be higher underneath and adjacent to TOWs in grassland compared to the surrounding open grassland (Chandler and Chappell 2008).

The overall effect on hydrology will be to reduce the amount of runoff (especially in smaller rainfall events) and to release water more slowly into water bodies. This can improve groundwater recharge, resulting in a positive impact on low flows. It also has the potential to reduce surface water and fluvial flood risk. Effects extend to rural areas. Modelling in Pontbren in Wales predicted that planting shelterbelts across the lower parts of grazed grassland sites could reduce peak flows by between 13 and 48% in this small sub-catchment (Jackson et al. 2008). However, in the larger 260 km^2 Hodder catchment, the reduction in the flood peak due to tree planting was reported to be 2%. Evidence from a number of studies indicates that tree planting can significantly reduce peak flood flows, flow volumes and time to peak at small scales (plot, field and very small catchment scales), but that the effect diminishes as the scale of the catchment increases (McIntyre and Thorne 2013).

2.1.5 Water quality and erosion control

As well as potentially reducing flood risk, TOWs can also enhance water quality and control soil erosion. Diffuse pollution from both agricultural and urban areas is a major cause of poor water quality and contributes in many places towards failures to meet Water Framework Directive targets. TOWs (and wider areas of woodland) are able to ameliorate diffuse pollution by trapping and retaining nutrients and sediment in polluted runoff (Nisbet et al. 2011). By intercepting rainfall they also reduce the potential for soil erosion and this effect is enhanced by the presence of leaf litter on the ground surface.

Studies in Poland have shown that tree shelterbelts and woodland strips are effective at reducing nitrate leaching and run-off from adjacent agricultural fields, thereby enhancing groundwater chemistry. Indeed, nitrate concentrations in groundwater within shelterbelts, or in pine and birch woodland patches, were reduced by 76-98% of the input compared to adjacent cultivated fields (Ryszkowski and Kędziora 2007). A number of studies have shown that belts of riparian woodland, typically 10-30m wide, are effective at removing almost all of the nitrate and phosphate pollutants in surface runoff, with the majority retained in the first 5m of the buffer zone (reviewed in Broadmeadow and Nisbet 2004). Shelterbelts can also be very effective at reducing pesticide spray drift and in removing sediment. Much more information on the importance of trees for managing water quality and quantity is provided in reviews such as Nisbet et al. (2011) and Woodland Trust (2012a).

2.1.6 Noise regulation

Noise can impact health, wellbeing, productivity and the natural environment. The World Health Organisation (WHO) has identified environmental noise as the second largest environmental health risk in Western Europe (after air pollution). It is estimated that the annual social cost of urban road noise in England is £7 to £10 billion (Defra 2013). In the UK about 10% of the population live in areas of excessive daytime sound levels, although up to 30% of the population express dissatisfaction in surveys of their local noise environment (HPA 2010). Major roads, railways, airports and industrial areas can all be sources of considerable noise.

The use of tree belts to reduce noise pollution has been a matter of debate for many years. Studies in many countries have shown that densely planted tree belts can reduce noise levels, but the effects are modest, with reductions of 2-4 dB typically recorded (Heisler 1977, Harris and Cohn 1985, Peng et al. 2014). Higher frequency noise is heavily attenuated by vegetation but there is virtually no attenuation of low frequency noise (Kalansuriya et al. 2009). Noise reduction is mostly due to the physical scattering of sound waves caused by tree trunks and absorption into the soil (Van Renterghem 2014). Note however, that there is some evidence to suggest that the presence of vegetation blocking views of a noise source such as a road can enhance the perception of noise reduction (e.g. Harris and Cohn 1985).

Densely planted and complex vegetation cover such as trees mixed with scrub is considered to be most effective, although any vegetation cover is more effective than artificial sealed surfaces. Noise absorption is linearly proportional to the width of the vegetation barrier (Kalansuriya et al. 2009), but there is no consistent effect of height. Overall, Van Renterghem et al. (2015) reported that a 15m wide tree belt provides equivalent noise reduction to a 1-2m high thin concrete noise wall and Van Renterghem (2014) provides guidelines on how tree belts can be optimised to reduce road traffic noise.

2.1.7 Shelter and shade for crops and livestock

Trees are used as shelterbelts to enhance the yield of crops grown in the sheltered microclimate created by a windbreak. Whilst the effects are greatest in drier regions and in drier years, shelter effects are evident throughout the world (Kort 1988, Nuberg 1998). Crops such as winter wheat, barley and rye are highly responsive to protection, whereas spring wheat, oats and maize respond to a lesser degree (Kort 1988). The mechanisms responsible for the yield increases have been identified to be reduced wind erosion, improved microclimate, increased soil moisture, and reduced crop damage (Kort 1988). Factors such as the height, permeability, orientation and location of the windbreak in the landscape determine the degree of shelter provided (Nuberg 1998). However, in cooler conditions shelterbelts can also shade the crop to the detriment of yield, hence local and regional variations in the effectiveness of shelterbelts are apparent. A comprehensive review of the benefits of shelterbelts for UK agriculture is provided in Donnison (2012).

Trees and shelterbelts are also important for sheltering livestock and have been used in the UK for centuries. Cold, wet and windy conditions stress new-born lambs and freshly shorn sheep leading to a decline in animal health. In addition, animals exposed to cold winds use more feed simply to keep warm and show increased vulnerability to disease (Woodland Trust 2012b). Conversely, all livestock are susceptible to heat stress and trees are very effective at providing relief through shading. Heat stress can affect milk yield and herd fertility of dairy animals, can reduce fertility in sheep, cause reduced feed intake and egg weight, and a lowered immune system in hens, and pigs are susceptible to sunburn as well as heat stress (Woodland Trust 2012b). Planting deciduous trees is recommended as they provide effective shade in the summer but block less of the sun in the winter than coniferous trees.

2.1.8 Supporting pollinators

Insect pollinators are essential for human survival and for the natural environment. They pollinate 75% of the native plant species in Britain (Ollerton et al. 2011) and directly contribute an estimated £603 million per annum to the British economy through the pollination of agricultural crops (Vanbergen et al. 2014). They also pollinate orchard, allotment and garden fruit and vegetables and are essential to the continuing existence of most wild plant species. They have high cultural value, both in their own right and through the maintenance of our countryside and gardens.

The majority of smaller tree species in the UK are insect pollinated. Many commonly planted roadside trees such as lime (*Tilia cordata*), and popular suburban species such as flowering cherries (*Prunus* spp.) provide significant floral resources for pollinators (Hausmann et al. 2016). TOWs also provide excellent nesting opportunities for pollinators, both within the trees and underneath. Within agricultural areas oilseed rape and field beans are the most commonly grown insect pollinated crops in the UK. These crops provide an abundance of food resources for a short time in spring, but to maintain pollinator populations, these insects also require nesting sites, shelter, and nectar sources before and after crop flowering. TOWs are able to provide these essential resources.

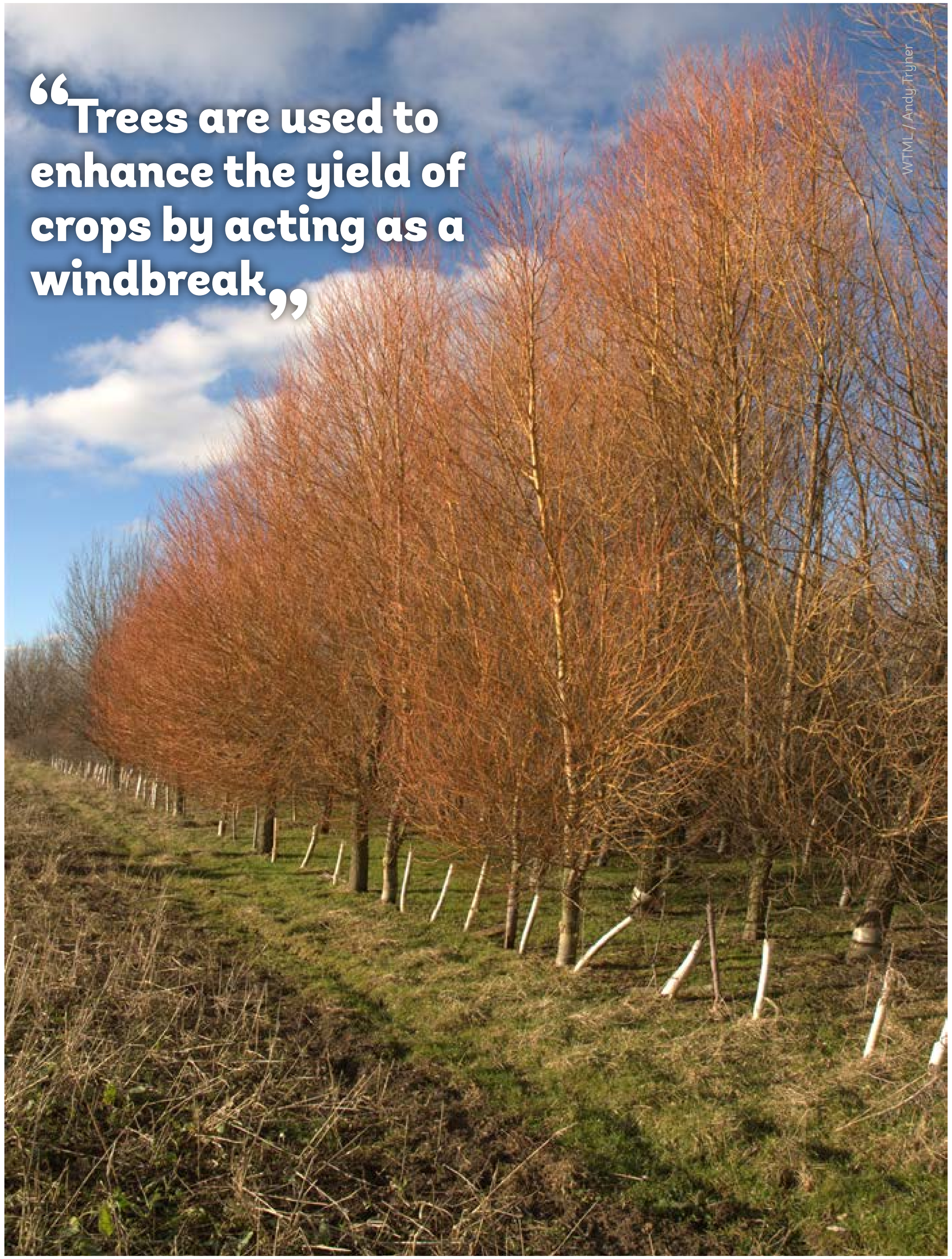
2.1.9 Pest control

There is increasing evidence to suggest that woody habitats and shelterbelts in agricultural landscapes can suppress invertebrate pests. Tsitsilas et al. (2006) found that the number of pest insects was low in shelterbelts and lower in adjacent pasture compared to further into the field, whereas the number of predatory mites and spiders was higher in shelterbelts and the adjacent pasture than further in. Shelterbelts with associated ground cover seemed to be particularly good at harbouring a diversity of beneficial organisms that suppress pest numbers in adjacent pastures. A major review by Bianchi et al. (2006) compiled a large number of studies that have reported similar findings. For example, in one study (cited in Bianchi et al. 2006) 60% of the alternative hosts of generalist parasitoids that control lepidopteran crop pests feed on trees and shrubs. Presence of alternative hosts and prey can increase parasitoid and predator populations, resulting in improved pest control. Woody vegetation may also act as sources of nectar and pollen, which can increase the effectiveness of natural enemies controlling pest insect populations (Bianchi et al. 2006). Many species of hoverflies (Syrphidae), for example, have larvae that eat aphids and other pest species, but require pollen and nectar sources as adults. Marino and Landis (1996) found that rates of parasitism of pest species were significantly higher in complex landscapes containing small fields with abundant hedgerows, trees and small woods, compared to more homogenous landscapes. Indeed, a meta-analysis showed that the presence of wooded habitats in the landscape resulted in a significant enhancement of natural enemy populations in 71% of studies, with only 4% showing the opposite effect (Bianchi et al. 2006).

2.1.10 Other benefits to agriculture

Trees outside of woods (TOWs) provide a number of additional benefits to agriculture not already described in previous sections, which are listed below:

- TOWs in rural areas are often associated with hedgerows, and when well managed these are important in providing stock enclosure and reducing spread of disease (especially bovine TB; Mathews et al. 2006)
- Habitat and cover for game birds
- Benefits for free-range poultry farms – trees have been shown to provide a wide range of benefits including improved ranging behaviour, lower parasite loads, reduction in injurious feather pecking, and enhanced egg quality (Woodland Trust 2014).



A landscape rich in trees

2.2 Cultural services

2.2.1 Landscape character, aesthetics and cultural heritage

Trees are often highly valued components of the landscape, contributing greatly to the aesthetics and landscape character of an area. Scattered trees and other types of TOWs are a fundamental part of the cultural landscape of the UK (Brown and Fisher 2009), providing character and local distinctiveness to many rural areas. TOWs can thus contribute greatly to the sense of place and identity of an area. Similarly, trees in towns, particularly tree-lined avenues and more mature trees, can be highly valued for the aesthetic benefits that they provide, or for screening undesirable views. Removal of such trees can generate strong emotions, seen for example in Sheffield, where a long-running and bitter dispute has been taking place over the felling of a number of street trees across the city (Guardian 2016, 2017).

Within urban areas many studies have examined residents' attitudes towards street trees, although the majority of these were conducted in the USA. In the UK, studies have shown a generally favourable attitude towards street trees. In surveys in Somerset and Torbay, residents rated the visual attractiveness of street trees as the most highly rated benefit, with overall benefits outweighing annoyances (Flannigan 2005). 'Enhances look of garden and home' and 'autumn colour' were also rated amongst the most important benefits of these urban street trees. In a comparison with studies from the USA, Schroeder et al. (2006) reported that although overall perceptions were similar, cultural or geographical differences were apparent. UK residents placed much less value on shade and preferred smaller trees with slower growth rates compared to residents in the USA (Schroeder et al. 2006).

Individual trees can also be important cultural assets contributing to the cultural heritage of an area. Ancient and veteran trees are often highly valued and may be connected to local history and folklore. Tree lines can also delineate ancient boundaries and other historic features. The importance and significance of individual trees is dependent upon their context and location, with Tabbush (2010) suggesting, for example, that old trees on village greens may have different cultural meanings compared to newly planted street trees.

2.2.2 Health and wellbeing

There is strong and growing evidence linking exposure to trees and the natural environment with enhancements in both physical and mental health and wellbeing. A large number of studies have examined the role of green space and the natural environment in general, and a significant subset of these has focussed specifically on trees. Some of the key studies are outlined here, but this is not comprehensive, so please refer to reviews such as Bird (2007) and O'Brien et al. (2010) for more complete coverage.

Short-term physical benefits of trees have been measured simply through sitting in a room with tree views, which promoted more rapid decline in blood pressure following a stressful activity than sitting in a room with no view (Hartig et al. 2003). The benefits of a view of trees extend to hospital settings, where Ulrich (1984), in a now classic paper found that after surgery, patients with a room with views of trees recovered quicker and required fewer painkillers than those with no view of trees.

Children's attention and cognitive function has been shown to benefit if they live in an urban area with views of trees. Girls, in particular, showed greater concentration, impulse control, and delayed gratification (Taylor et al. 2002). Poor school achievement and crime are associated with low levels of self-discipline, impulsive behaviour, immediate gratification and inattention that have all been shown to improve by contact with nature. Children living in areas with more street trees have also been shown to have lower prevalence of asthma (Lovasi et al. 2008). Trees have even been shown to affect pregnancy, reducing the risk of poor birth outcomes. Donovan et al. (2011) found that a 10% increase in tree-canopy cover within 50m of a house reduced the number of small for gestational age births by 1.42 per 1000 births.

Access or views of trees enhance people's long-term mental health. One British study examined the effects of moving to greener and less green urban areas on mental health over a number of years (Alcock et al. 2014). They revealed that individuals who moved to greener areas had significantly better mental health following the move, whereas individuals who moved to less green areas showed significantly worse mental health in the year preceding the move and returned only to the baseline level in the years following the move. Kuo and Sullivan (2001a) reported that residents living in buildings with little surrounding vegetation reported more aggression and

Exposure to trees and the natural environment has been like to enhancements in both physical and mental health and wellbeing violence than did their counterparts in greener buildings. In addition, levels of mental fatigue were higher in buildings with no surrounding vegetation, and this mental fatigue was accompanied by aggression.

Trees also provide benefit through promoting physical activity, which is of key importance for the promotion of good health. Parks with trees are used more than those without, streets with trees have more bicycle traffic, and Borst et al. (2008) revealed a positive relationship between the presence of street trees and preferred walking routes for elderly people. Trees are an important component of 'sense of place' and hence in creating a sense of belonging and identity, which in turn has a positive effect on mental health (Bird 2007). Also, by encouraging greater use of outdoor spaces, trees can indirectly enhance social relations and community cohesion.

Finally, in a fascinating study from the USA, Donovan et al. (2013) utilised a natural experiment to test whether the loss of a large number of trees influenced mortality related to cardiovascular and lower respiratory diseases. The emerald ash borer (*Agrilus planipennisis*) is a wood-boring beetle native to East Asia that first arrived in North America in the 1990s and was subsequently identified in 2002 as the cause of widespread ash (*Fraxinus* spp.) mortality in the Detroit area. It causes virtually 100% mortality in North American ash species and by 2012 it had killed approximately 100 million trees in the USA and was spreading rapidly. Donovan et al. (2013) examined the relationship between emerald ash borer presence and mortality across counties in 15 U.S. states, while controlling for a wide range of demographic covariates. They found a significant increase in mortality in areas infested with the beetle. The magnitude of this effect was greater as infestation progressed and in locations with above average household income. In total across the study area, the beetle was associated with an additional 6,113 deaths related to illness of the lower respiratory system, and 15,080 cardiovascular-related deaths (Donovan et al. 2013). It's interesting to note that the proportion of ash in relation to total canopy cover in each county was between 1.5 and 7.9%, hence these effects have been found with only a modest reduction in overall tree cover.

Note that the emerald ash borer has recently become established in the Moscow region of Russia and is now spreading towards central Europe at a rate of 30-41 km a year (Straw et al. 2013). It is expected to reach the UK eventually. The main ash species found in the UK and Europe (*Fraxinus excelsior*) is susceptible to the beetle and, as in the US, may suffer 100% mortality. Ash in the UK is already suffering from ash dieback and the two diseases together are predicted to be catastrophic for the ash population. In the UK, ash is thought to be the most common tree species outside of woods (and the second most common species in woodland), and makes up a higher proportion of the overall tree population than in the US.

2.2.3 Crime and safety

There is evidence to suggest that in urban areas, the presence of trees can be used to deter crime and anti-social behaviour. Fewer crimes were reported in locations with greater amounts of vegetation, whilst accounting for other factors (Kuo and Sullivan 2001b), while surveys have revealed a clear preference for the presence of trees (Kuo et al. 1998). Donovan and Prestemon (2012) also reported a decreased incidence of crime when street trees were present, and suggested that the presence of trees was perceived as indicating a more cared for environment. Similarly, Burden (2006) has suggested that trees improve security due to better use of these spaces and hence increased surveillance. In a study in Baltimore (USA) Troy et al. (2012) found that a 10% increase in trees roughly equalled a 12% decrease in crime and that the magnitude was 40% greater for trees on public than on private lands. They noted, however, that the relationship between tree cover and reduced crime was reversed where trees were growing on abandoned land. Similarly, a number of studies report that dense vegetation in urban areas was not favoured as this is regularly linked with increased concerns over safety and fear of crime. Thus street trees and other types of widely spaced trees are perceived differently and much more favourably than woodland or other dense vegetation in urban areas.

Roadside trees also have a marked impact on road safety, although the effects are complicated and depend on locational factors relating to the road and the positioning of the trees. Dumbaugh (2005) revealed that planting street trees had a positive effect on reducing the frequency and severity of crashes, even though this was not the original intention of the plantings. The positive effect of street trees on driver safety was also reported by Naderi et al. (2008), who presented two theories to explain these findings. The first is based on Berlyne's theory of visual complexity (Berlyne 1971), which states that different levels of visual complexity affect attention and alertness, with maximum attentiveness occurring in visual landscapes that are diverse but not overwhelmingly so, and relatively simple but not to the point of being boring. The second theory relates to work on the aesthetic dimensions of city legibility developed by Lynch (cited in Naderi et al. 2008), which suggests that tree-lined streets present a defined 'edge' between the street and the surrounding area, enhancing legibility, resulting in enhanced comfort and reduced driver stress. Lower stress is known to have a positive effect on human performance.

Speed perception is also affected by the presence of roadside trees. Martens et al. (1997) reported that on rural roads, speeds were underestimated much more on open roads compared to those lined with trees. Similarly, Burden (2006) reported that speeds on urban road sections with street trees were 3 to 15 mph slower than on adjacent sections with no trees. The use of trees to reduce road speeds is being investigated by the Department for Transport in the UK where a trial in four villages in Norfolk found that creating an avenue of trees and hedges had a dramatic impact on motorists' behaviour. Drivers reduced their speed because of a cut in their peripheral vision, with a 20% drop in the number of motorists driving at 40 to 60mph and overall speeds falling by 1.5% (Telegraph 2011). However, crashes that involve collisions with trees are twice as likely to result in a fatality and account for 1 in 12 road deaths in the UK (AA 2010), hence the placement of trees relative to particular road features can be an important consideration.

In addition to driver safety, roadside trees create a safer environment for pedestrians by providing a visual and physical barrier between pedestrians and road users. There is also some evidence from the USA to suggest that trees reduce incidences of road rage through the calming effect that trees have on drivers (Burden 2006).

2.2.4 Other cultural services

Trees outside of woods (TOWs) provide a number of additional cultural and socio-economic benefits, which are briefly summarised below:

- Privacy – TOWs can enhance privacy (Roy et al. 2012), which is considered to be an important benefit of urban street trees in surveys of UK residents (Flannigan 2005).
- Stronger and more stable communities – this is likely to occur due to the fact that public areas containing trees are better used and cared for than areas with no trees, a phenomenon discussed in the section on safety. There is also a suggestion that neighbourhoods with trees have higher property occupancy rates and reduced turnover of households, leading to a more stable community (Dandy 2010).
- Contact with nature - in a UK survey of residents' views, 'brings nature closer' was considered to be the second most highly rated benefit of urban street trees (behind 'pleasing to the eye') (Flannigan 2005) and this was also rated highly in the USA (Schroeder et al. 2006). Urban trees enable people to view wildlife such as squirrels, birds and insects right in the heart of cities.
- Education opportunities – TOWs may provide a setting for learning outdoors, which has many developmental benefits, and can themselves be a source of study. In addition, views of the natural environment from the classroom have been found to increase concentration, improve results and decrease time off due to illness (Bird 2007). Many schools are not large enough to contain woodland in their grounds, but a small number of trees and associated semi-natural habitats are much more feasible.
- Quality of life – a number of studies have demonstrated an increase in quality of life due to the presence of urban trees (Roy et al. 2005).
- Spiritual value
- Trees also have an important role in increasing property value and attracting and adding value to business, and these are discussed further in Section 5.2.5.

2.3 Provisioning services

Provisioning services provided by trees outside of woods (TOWs) are currently much less significant than regulating or cultural services. However, provisioning services have traditionally held a much more prominent role and there is potential for that role to become more prominent again in the near future. Historically, all natural capital assets in the countryside were utilised, including isolated trees, parkland and farm woodland. These would have been important sources of timber, fuel, fodder, fruit, nuts and berries, but many of these practices have now ceased.

Opportunities now exist to reinstate some of these practices along with the chance to develop new 21st century possibilities. Farm woodland and small areas of trees can be used to produce timber and fuel, together with a wide range of other ecosystem services, and new plantings can be promoted through environmental stewardship. Fruit and nuts can be harvested from street trees and although such areas are prone to high pollution levels, these are likely to be safe for consumption (von Hoffen and Säumel 2014). But it is the development of biofuels that is a particular focus of attention at present, with targets set to increase the use of renewable, carbon-neutral and home-grown energy sources. Existing trees can be used to produce woodchip for residential heating boilers, which has considerable environmental benefits over fossil fuels (Esteban et al. 2014). Some areas of farmland have been converted to biofuel production, but this can be controversial due to the potential conflict between food and energy security. One potential solution is to use road verges for the production of short rotation willow (Salix) and poplar (Populus) coppice. A recent study of the potential for using road verges in Holland by Voinov et al. (2015) showed that the Energy Return on Energy Invested (EROEI) considering the whole lifecycle of a scheme was good and compared favourably with other renewable energy sources and with fossil fuels. Furthermore, such schemes provided a number of additional benefits such as biodiversity enhancement, carbon sequestration, water quality improvement and storm water management (Rowe et al. 2009). Salix in particular is especially well suited to deliver these additional ecosystem services benefits. Not all road verges can be used, due to road safety requirements, but considerable opportunities were considered to exist, especially along the major road network which has larger verges (Voinov et al. 2015). Road verges have the additional advantages of being easy to access and have a large edge to interior ratio, which is considered ideal for short rotation coppice (Rowe et al. 2009).

3. Disservices provided by TOWs

Trees outside woods (TOWs) clearly provide many benefits to society; however, they can also provide disservices. Disservices are 'functions of ecosystems that are perceived as negative for human-well-being' (Lyytimäki and Sipilä 2009). These range from relatively minor nuisances about which people might complain, for instance, unsightly unmanaged trees and trees creating a sticky residue on parked cars, to potentially serious health effects caused by their pollen and the contribution to poor air quality. Table 3 lists disservices that can be produced by trees and categorises them as either social, visual and aesthetic, or environmental, and lists economic and health implications of these disservices. This list is unlikely to be exhaustive but it certainly covers the main issues and has been compiled from the most recent reviews of this subject.

Much of the literature focusing on tree disservices is in relation to urban, and therefore, mainly street trees. This is not surprising given that more people live in cities than rural areas to experience disservices, and that the creation of atmospheric pollutants from human activity is highest in cities and is an issue that exacerbates many tree disservices. We review the scientific literature on tree disservices below, focusing on those that are thought to be of most concern.

3.1 Trees causing environmental problems with health implications

Increasing pollution is of major concern especially in large urban areas. Trees are considered to be effective at the removal of pollutants, but research shows that the issue is more complex depending on where trees are located, which species are used, their geometry, urban morphology around trees, and the level and type of atmospheric pollutants present.

3.1.1 Trees trapping pollutants at street level

Roadside urban trees have been shown to increase pollutant concentrations locally (Gromke and Ruck 2007, 2009, 2012, 2015, Gromke 2011, Wania et al. 2012, Vos et al. 2013). This occurs as trees in road canyons (roads with buildings on either side) can obstruct the wind flow that provides ventilation and dilutes pollutants. Vos et al. (2013) showed that this aerodynamic effect is stronger than the capacity of vegetation to remove pollutants (this study focused on trees as well as shrubs in various geometries and configurations within road canyons). While this is a significant issue, it is important to note that these studies are focused on roadside trees in road canyons, and on local air quality. Trees in roads that are not canyons and other locations (e.g. urban parks) may not have this effect, and roadside urban trees have been shown to have a positive effect on average air quality across cities.

Table 3: The ecosystem disservices provided by trees and their health and economic implications.

Tree ecosystem disservices
Social
Fear of: causing crime, disease, insects or other animals
Fear of trees, forests and associated environments
Visual and aesthetic
Create a dark environment
Perceived as 'messy' or 'ugly'
Obscuring views
Sticky residue on parked cars
Environmental
Increasing water and energy consumption
Generate pollen
Generation of green waste
Releasing carbon through maintenance practices
Releasing Volatile Organic Compounds (VOCs) and increasing ozone and smog
Slowing of air currents causing pollutants to settle at street level
Displacing native species
Dropping branches, leaves, flowers, seeds
Tree roots crack the pavements, damage to property, cars and urban infrastructure
Causing drainage issues
Can fall on power lines
Obstructing traffic on roads and pavements
Concealing traffic signs and street lighting
Obstructing use of space (for parking etc.)
Health implications
Increase in sensitisation to tree pollen
Respiratory health effects from pollen and increased pollutants in atmosphere
Attack by associated insects or other animals
Risk of trees falling on people
Direct economic costs
Costs of planting and establishment
Irrigation, maintenance, pruning, crown thinning, removal
Cost of management and administration
Tree induced damage repairs to urban and rural infrastructure
Indirect economic costs
Costs for health implications of allergy and increased air pollution
Leaf and debris clear-up
Release of CO_2 on decomposition
Reduction in property values
Travel delays and accidents
Opportunity costs
Space that trees occupy can't be used for other activities e.g. parking, cycle lanes
Building/development restrictions from listed trees

Sources: Roy et al. (2012), Gómez-Baggethun and Barton (2013), Delshammar et al. (2015), Vogt et al. (2015).

3.1.2 Release of Volatile Organic Compounds (VOCs)

Trees can emit VOCs, e.g. isoprene, monoterpenes, ethane, propene, butane, acetaldehyde, formaldehyde, acetic acid and formic acid (Gómez-Baggethun and Barton 2013). This is usually due to environmental stress e.g. high light intensity, temperatures and low water availability (Defra 2010). VOCs combine with human-made nitrogen oxides (NO_X) (e.g. from traffic exhaust) and produce pollutants such as particulate matter (Lin et al. 2013) and ozone (O_3). The consequences are a decrease in air quality and an increase of ozone pollution in smog episodes, with implications for respiratory health in humans.

Whether or not a tree produces ozone, or indeed particulate matter, is likely to depend on its context, e.g. whether it is a roadside, urban or rural tree. Roadside urban trees are likely to produce ozone if in street canyons as NO_X concentrations are likely to be high. In areas where there are low concentrations of NO_X, e.g. rural areas, VOCs may actually remove ozone (Calfapietra et al. 2013, Salmond et al. 2016). However, VOC emissions are temperature dependent, emissions being lower in lower temperatures. Consequently, it is possible that urban trees can lower ozone levels in urban areas if tree cover is increased (as trees can lower air temperature). The interaction between VOCs, urban pollution and their influence on ozone formation, the effects of ozone on the biochemical reactions and physiological conditions leading to VOC emissions is still not fully understood (Calfapietra et al. 2013, Salmond et al. 2016).

VOC emission rates vary between tree species. Spruce species (particularly Sitka), sycamore, poplar, willow, and oak species have the highest VOC emission rates (Donovan et al. 2005). However, it is not yet known whether these groups of species will contribute to an overall net formation of ozone in cities (Defra 2010). Clearly increases in pollutants has the potential to have negative health effects, as mentioned above, particularly for street-level commuters or urban dwellers, but the direct links between VOC emissions from trees and negative health impacts are yet to be made (Salmond et al. 2016).

3.1.3 Pollen

Pollen is released from tree blossom into the atmosphere, and has been identified as an aeroallergen. It is thought to cause conditions such as allergic rhinitis, exacerbation of asthma and eczema (Salmond et al. 2016). To date research on the link between trees, particularly urban trees, asthma and allergy has been limited. One study (Lovasi et al. 2013) that has begun to explore this relationship found that children at the age of 7 were more sensitive to tree pollen when their mothers had lived in areas with greater tree cover during pregnancy.

Pollen release is seasonal and occurs at different times of the year depending on the species (see Salmond et al. 2016). People can be more susceptible to pollen from some tree species than others. Most of the allergenic tree pollen in the UK and Europe is from birch species, but other species such as London plane can also cause problems. To complicate matters, research has revealed an interaction between atmospheric pollutant concentrations and the health response to pollen (D'Amato 2000, Salmond et al. 2016). Urban dwellers appear to be more affected by pollen allergy than those who live in rural areas (D'Amato 2000). Increases in respiratory allergies caused by pollen tend to coincide with streets that have high levels of emissions from traffic. This is thought to occur because the air pollution that people are exposed to, before the tree pollen season, can lower the level of pollen required to trigger allergy symptoms (D'Amato 2000). Health effects of tree pollen production may also be exacerbated by climate change, meaning that pollen release occurs earlier and for a longer period. More research is required to understand the effect of the spatial positioning of trees, tree species and the link to pollen exposure, air quality and health.

3.2 Impact on the built environment

Trees can often cause damage to urban and rural infrastructure. This can occur because trees offer roosting opportunities to birds, and their excrement can speed up corrosion (Lyytimäki and Sipilä 2009). Tree roots can also break up pavements and roads, indirectly cause building subsidence when they grow in search of water and cause shading (Vogt et al. 2015). Tree falls can block roads and cause damage to power lines. Vegetation may obscure road or business signs with associated road accidents and customer losses (Lyytimäki and Sililä 2009, Vogt et al. 2015). Leaf fall from trees can cause problems with transport infrastructure, causing safety concerns and delays. The costs associated with trees interfering with infrastructure occur when an inappropriate species of tree is used, it has not been planted correctly, or its location is unsuitable (Vogt et al. 2015).

3.3 Social perceptions and aesthetic values

Areas of trees can be perceived as unsafe, especially at night (Koskela and Pain 2000; Jorgensen and Anthopoulou 2007). High density tree and shrub planting is thought to cause security and safety concerns especially where vegetation blocks views (Nasar and Fisher 1993). However, studies since show there is no evidence of crime rates being higher (Kuo and Sullivan 2001b), and that green space in general can be associated with a greater sense of safety, apart from in very dense urban settings (Maas et al. 2009; see Section 2.2.3). The wildlife that may be attracted to the trees e.g. insects and birds, can irritate, frighten or cause anxiety (Bixler and Floyd 1997, Lyytimäki and Sipilä 2009). The excrement from birds is considered unsightly and can cause a nuisance when it covers cars. Trees need to be well maintained otherwise some people complain about them being 'messy' or 'ugly'. When near dwellings they may block views out of windows (Lyytimäki et al. 2008).

4. Which trees to plant where?

The previous two sections have illustrated that trees outside woods (TOWs) can provide a large number of benefits to society, but that they can also have a negative impact, producing disbenefits. Disbenefits often occur as a result of the wrong type of tree being planted in the wrong place. There is therefore increasing interest in ensuring that the right species of trees are now planted in the right places and this comes down to a combination of location and tree species characteristics.

Location effects have been mentioned throughout the earlier sections and include for example that:

- Trees planted in urban canyons (i.e. in dense urban areas with high rise buildings on both sides of the street) can exacerbate air pollution at ground level.
- The effect of shade on buildings is highly dependent on where the trees are planted in relation to the buildings. In addition, the size, shape and species of tree plays a role, as large coniferous trees, especially to the south, tend to provide unwanted shade in the winter.
- Large trees close to houses are often unpopular with homeowners.

There are many other locational effects that should be considered when planting TOWs, but it is beyond the scope of this review to describe these further. McPherson et al. (2007) provides recommendations for selecting and placing trees for a variety of different aims.

There is a growing body of information on the characteristics of different tree species in relation to ecosystem service delivery, and hence their appropriateness for planting in different locations. For example, O'Sullivan et al. (2017) have just published a review of trees in road verges that includes an assessment of the key ecosystem services provided by different tree species collated from previously published datasets. Information from this review is shown in Table 4 and includes:

- **Air quality amelioration,** which is a function of the relative ability of different tree species to absorb particulate matter (PM), and also the relative amount of VOCs released. The best species for planting in urban streets would be those that have high performance for absorbing PM, but low VOC emissions, such as silver birch (Betula pendula).
- Trees planted in urban areas dominated by sealed surfaces (such as street trees and trees planted in civic spaces) need to be **drought tolerant** and Table 4 indicates the degree of suitability. However, note that high performance in drought tolerance trades-off against water uptake rates and thus flood alleviation (O'Sullivan et al. 2017). Drought tolerance, together with **winter hardiness**, is also linked with climate change resilience.
- **Biodiversity value** incorporates information on value for mycorrhizal fungi, foliage invertebrates (richness and biomass), leaf litter communities, pollinators, provision of fruits and seeds and epiphyte communities, taken from the scientific literature.
- **Carbon sequestration** is a function of growth rate and wood density (both shown on Table 4) whereby faster growth rates and high wood densities are advantageous.
- Many species planted in the UK and approved for use on road verges and urban areas are non-native. Native trees should always be preferred, and the natural distribution of each species is shown in Table 4.

Table 4: Relative value of tree species commonly planted in urban areas of Britain and Europe for key ecosystem services including biodiversity value (from O'Sullivan et al. 2017). Scores are assigned from previously published datasets and for each performance measure (except drought tolerance and winter hardiness) are allocated into three approximately equal sized groups, with +, ++ and +++ respectively indicating low, medium and high performance. For drought tolerance and winter hardiness +, ++ and +++ respectively indicate problematic or not very suitable species, suitable and very suitable species.

Species name		Native Distribution	Air quality		Drought tolerance	Winter Hardiness	Biodiversity value	Growth rates	Wood density
			PM	VOCs					
Acer campestre	Field maple	Europe, N. Africa and W. Asia	++	+	+++	+++	++	+	+++
Acer platanoides	Norway maple	Europe and W. Asia (not UK)	+	+	++	+++		+++	++
Acer pseudoplatanus	Sycamore	Europe and W. Asia (not UK)	+	+++	+	+++	+++	+	+++
Aesculus hippocastanum	Horse chestnut	Europe (not UK)	++		+	++	+	+	++
Alnus cordata#	Italian alder	Europe (not UK)		++	++	++		+++	+
Alnus glutinosa	Alder	Europe, N. Africa and W. Asia		+	+	++	++	++	+
Alnus incana	Grey alder	Northern temperate (not UK)		++	+++	+++			+
Betula ermanii	Erman's birch	E. Asia							++
Betula pendula	Silver birch	Europe and W. Asia	+++	+	++	+++	+++	+++	++
Carpinus betulus	Common hornbeam	Europe and W. Asia	++		++	+++	+	+	+++
Castanea sativa	Sweet chestnut	Europe and Asia Minor (not UK)			++	++	+		++
Catalpa bignonioides	Indian bean tree	N. America			+	+			+
Cedrus atlantica	Atlas cedar	N. Africa			+++	+			+
Chamaecyparis lawsoniana	Lawson cypress	N. America		+					+
Corylus colurna	Hazel	Europe and W. Asia		++	++	++	++	++	++
Crataegus laevigata	Midland hawthorn	Europe			+	+++	+++	+++	+++
Crataegus monogyna	Common hawthorn	Europe, N. Africa and W. Asia		+	++	+++	+++	+	+++
Cupressocyparis leylandii	Leyland cypress	N. America		++	++	++		+++	
Fagus sylvatica	Beech	Europe	+		+	++	+++	+	+++
Fraxinus excelsior	Ash	Europe and W. Asia	+	+	++	++	++	++	+++
Ginkgo biloba	Ginko	E. Asia			+++	++			
Gleditsia triacanthos	Honey locust	Central and N. America			+++	++			+++
Gymnocladus dioica	Kentucky coffee tree	N. America			++	++			++
Ilex aquifolium	Holly	Europe, N. Africa and W. Asia		++			++	+	+++
Juglans nigra	Walnut	N. America	++				+		++
Larix decidua	Larch	Europe (not UK)		+			++		++
Liquidambar styraciflua	Sweet gum	Central and N. America			++	+			++
Liriodendron tulipifera	Tulip tree	N. America			+	++			+
Malus	Apple	Northern temperate		++	+	++	+++	+	+++
Parrotia persica	Persian ironwood	Central Asia							
Picea abies	Norway spruce	Europe (not UK)					++		+
Pinus nigra	Black pine	Europe, N. Africa (not UK)		+	+++	+++		+++	
Pinus sylvestris	Scots pine	Europe and W. Asia	+++		+++	+++	++	+++	+
Platanus x hispanica	London plane	Hybrid - N. America/E. Asia			+++	++	+	++	+++
Populus tremula	Aspen	Europe and Asia	++	+++	++	+++	+	+++	+

Species name		Native Distribution	Air quality		Drought tolerance	Winter Hardiness	Biodiversity value	Growth rates	Wood density
			PM	VOCs					
Prunus cerasifera	Plum	Europe and Asia Minor (not UK)			+++	++	+++		++
Prunus x hillier	Cherry hybrid	Hybrid - E. Asia/E. Asia	+	++					
Prunus laurocerasus	Laurel	N. America		+	+	+++			
Prunus spp.	Cherry tree spp.	Northern temperate					+++	+++	++
Pterocarya fraxinifolia	Caucasian walnut	W. Asia			+	+			+
Pyrus calleryana	Callery pear	E. Asia	++		+++	++		+++	+++
Quercus cerris	Turkey oak	Europe & Asia Minor (not UK)			+++	++	+		+++
Quercus ilex	Holm oak	Mediterranean Basin					+		
Quercus petraea	Sessile oak	Europe and W. Asia		+++	++	++	+++		+++
Quercus robur	English oak	Europe and W. Asia	++	+++	+	+++	+++	++	+++
Quercus rubra	Red oak	N. America		+++	++	++			++
Robinia pseudoacacia var. frisia	False acacia	N. America	+		+	+++	+		+++
Salix alba	White willow	Europe and Asia		+++	+	+++	+++	++	+
Salix caprea	Goat willow	Europe and Asia		+++	++	+++	+++	++	+
Salix fragilis	Crack willow	Europe and W. Asia	+++	+++			+++	++	+
Sambucus nigra	Elder	Europe and W. Asia		++				+	++
Sequoiadendron giganteum	Giant redwood	N. America							+
Sorbus aucuparia	Mountain ash	Europe, N. Africa and W. Asia		++	+	+++	++	++	++
Sorbus intermedia 'Brouwers'	Swedish whitebeam	Northern Europe (not UK)	++		++	+++		++	++
Sorbus x arnoldiana	Rowan hybrid	Hybrid - East Asia/Europe, N Africa and W. Asia			+	+++		++	++
Syringa vulgaris	Lilac	Europe (not UK)		+++	++	+++		+	
Taxus baccata	Yew	Europe, N. Africa and W. Asia	++				+	+	++
Tilia	Lime spp.	Northern temperate		++			++	++	+
Tilia cordata 'Winter Orange'	Small leaved lime var.	Europe and W. Asia	+		++	+++	++		+
Tilia cordata x mongolica	Lime hybrid	Hybrid - East Asia/Europe and W. Asia						++	+
Ulmus 'New Horizon'	Elm Hybrid	Hybrid - E. Asia/E. Asia	++	++				+	+++

5. Valuing the benefits of TOWs

Trees outside woods (TOWs) clearly provide a large number of services to society, as well as some disservices. Unfortunately, however, the vast majority of the benefits are not easily given a monetary value. If TOWs are not valued, but are merely seen as a cost, then there is a risk that they start to be viewed as a liability rather than an asset and may gradually be removed and not replaced. Estimating the economic benefits of trees is thus becoming increasingly important, not least because it can provide a monetary value that can be compared to maintenance and planting costs to directly justify tree budgets. Here we set out a range of possible valuation methods, the results of assessments that have used these methods to place a monetary value on trees, and an evaluation of the overall value of trees when taking into account planting and maintenance costs.

5.1 Valuation methods

Very few of the services provided by TOWs can be valued using existing markets, with the exception of the provisioning services (Section 2.3), such as timber, wood fuel and other bioenergy uses. A range of methods have therefore been developed to value some of the other services provided by trees, for which there is not currently a market, many of which have been packaged into tools for use by practitioners. The key tools and methods that are currently available in the UK are outlined briefly below.

5.1.1 i-Tree Eco – is a software package that has been developed over many years by the United States Department of Agriculture Forest Service to provide an assessment and valuation of some of the benefits of urban forests or individual trees. It is designed to use field data from complete inventories of trees or randomly located plots throughout a community, along with local hourly air pollution and meteorological data to quantify urban forest structure, environmental effects, and value to communities (i-Tree 2017). It provides an economic value of the benefits that each individual tree provides in relation to air pollution removal, carbon storage and sequestration, and avoided runoff, and also incorporates the Council of Tree and Landscape Appraisers (CTLA) method of estimating replacement value described below. Note that the air pollution removal calculations take into account VOCs and other pollutants emitted by trees to provide the net benefit, and the carbon calculations also provide net benefits taking into account dead and dying trees. A fully UK compatible version was released in 2016, opening up the possibility to perform economic assessments of TOWs much more easily and quickly.

5.1.2 CAVAT – or Capital Asset Value for Amenity Trees was developed by the London Tree Officers Association and was designed as an asset management tool for trees that are publicly owned, or of public importance (Neilan 2010). CAVAT works by calculating a unit value based on the diameter of the trunk, and then adjusts this value to reflect the degree of benefit that the tree provides to the local population. This takes into account the nearby human population density, accessibility, functionality (based on crown size and condition), relative contribution to amenity and appropriateness to the location, and life expectancy. The CAVAT method is regularly used to set levels of compensation when trees are damaged or destroyed.

5.1.3 Helliwell – was first published in 1967 and has been endorsed by the Tree Council and the Arboricultural Association. Its main aim is to aid practical planning and management of woodlands and urban trees by evaluating their relative contribution to the visual quality of the landscape (Helliwell 2008). The method is based on expert judgement and focuses on valuing the visual amenity (aesthetics) of a tree. It allocates points for six different aspects of amenity, and combines these points to give an overall comparative score, which is then multiplied by a unit value to arrive at a monetary value.

5.1.4 CTLA – Council of Tree and Landscape Appraisers in the USA have produced a series of formulas and methods for calculating aspects of tree value, the most widely used of which is to calculate the cost of replacing a tree. The replacement cost is based on four variables: trunk area, species, condition and location.

5.1.5 Treezilla – is primarily a citizen science project and resource that uses the i-Tree Eco approach, rather than a separate method. Treezilla was developed by the Open University, in partnership with Forest Research and Treeconomics, with the ambition of mapping and valuing every tree in Britain. Once details for a tree are logged, it automatically calculates monetary values for air pollution removal, carbon storage and sequestration, avoided runoff, and energy savings, using the same approach as i-Tree Eco.

5.1.6 Other tools – a growing number of tools are being developed to assess and value the ecosystem services delivered by a range of habitats or types of green infrastructure and some of these could be used to value TOWs. Natural England (2013) provides a review of some of these tools, including:

- InVEST – Integrated Valuation of Environmental Services and Tradeoffs
- GIVT – Green Infrastructure Valuation Toolkit
- CNT – Centre for Neighbourhood Technology Chicago, Guide to valuing Green Infrastructure

A number of additional ecosystem services assessment tools are available and can be used to quantify a range of benefits provided by TOWs, together with other habitats, but do not provide a monetary valuation. The most useful of these are:

- EcoServ GIS – developed by the Wildlife Trusts
- LUCI – Land Utilisation and Capability Indicator, developed by CEH and partners

5.1.7 Other environmental economics approaches

– In addition to the standalone tools described above, additional aspects of the monetary value of trees can be assessed using a number of environmental economic approaches. One of the most potentially useful is hedonic pricing, a revealed preference technique, which is especially useful for calculating the impact of trees on property prices. Stated preference approaches can also be useful to determine the public's willingness to pay for trees and the benefits that they provide.

5.2 Valuation results

Growing use of the tools described in the previous section, together with standalone economic assessments, is starting to build up an evidence base of the value of trees outside woods (TOWs). Note, however, that virtually all of the evidence relates to urban trees, especially publicly owned trees in streets and parks, and almost no valuations have been performed on rural TOWs. This is clearly an area that requires further study.

To examine the economic benefits of TOWs we have reviewed studies from around the world that have applied similar techniques (especially i-Tree). We have also compiled the results of all the major i-Tree assessments performed on 8 towns and cities in Great Britain, along with one rural roadside case study. The results of the British monetary assessments are shown in Table 5, and a summary of the value per tree from the UK studies, together with results from global studies are shown in Table 6. All international studies have been converted into sterling using January 2017 exchange rates to enable comparison, although the exchange rate will have some bearing on this comparison. A brief outline of how each ecosystem service is valued in the UK is provided below, followed by key findings from the UK and international studies. Note that the UK urban studies assess all trees within the study areas, hence include urban woodlands in addition to TOWs.

5.2.1 Air quality amelioration

The capacity of each individual tree to remove air pollution can be calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter, based on equations from the literature. This can then be valued in the UK using guidance from Defra that provides estimates of the damage costs per tonne of emissions (Defra 2015b). These are social damage costs based on avoided mortality and morbidity. Figures are not available for some pollutants and for these cases i-Tree eco supplements the UK costs with US externality cost prices. The UK social damage costs vary depending on the location of the study area, with costs being much higher in large urban areas than for more rural areas.

The annual monetary value of air quality amelioration (pollution removal) per tree in the UK ranged from £0.34 in Torbay to £14.97 in London (Table 5) and in the global studies values ranged from £0.46 in Berkeley, USA (McPherson et al. 2005) to £28.28 in Adelaide, Australia (Killicoat et al. 2002). Note that the value for Torbay may be lower than other UK studies as it was the first to be completed and used US externality values for each tonne of pollutant, which are on average lower than UK values. Varying results across the remaining studies from the same country are probably due to a combination of different pollution levels, tree sizes and tree species, as well as the higher social damage costs in the larger cities. London, for example, has high air pollution levels across the city, especially particulate matter levels, which is likely to drive the higher values. It also has a relatively mature tree stock compared to many of the other UK towns and cities, hence these larger trees are able to remove more pollutants. The negative value from Berkeley was due to the high emission of VOCs from the tree species present there, which counteracted the absorption of other pollutants. The value of rural roadside trees, in the only study of its type, was assessed at £2.02, which sits in the middle of the range of values from the UK urban areas. When the pollution removal values are summed across an entire city, the total values can be extremely high, often into the millions of pounds (Table 5). London is an outlier due to its size, but here the total value of air quality amelioration amounts to £126.1M per year, a highly significant benefit.

5.2.2 Carbon sequestration

The amount of CO_2 captured by each tree can be calculated based on the species, age and size of the tree. The monetary value is then calculated by multiplying this amount by the UK non-traded carbon price (DECC 2015) which is based on the cost of mitigating carbon emissions. This value is the same across the UK.

The value of carbon sequestration was fairly consistent across the UK studies, ranging from £0.84 in Wrexham to £1.80 per tree per year in London (Table 5). The mean value of a rural roadside tree was also within this range (£1.51). The differences that do occur will be a result of different species and age characteristics of the tree stocks. A slightly wider range from £0.20 in Los Angeles to £3.52 in Davis, USA was evident in the international studies (Table 6), but these studies may have differed in the carbon price that they used, as well as differences in tree stock. Annual values summed across whole cities were again large, ranging from c. £300,000 in Wrexham to c. £15.2M in London based on 2016 carbon prices.

5.2.3 Avoided runoff

The volume of rainfall that can be intercepted by each tree is first calculated based on the scientific literature. In urban areas, avoided runoff can then be valued based on the standard volumetric rate per cubic metre charged for sewerage by the local water company, as it is likely that most water that is not intercepted would end up in the drainage system. This typically ranges from about £0.81 to about £1.66 per m^3 in the existing UK studies. For rural areas, however, this assumption does not hold, as rainwater will not necessarily enter the drainage system. There is no single value for the cost of rural runoff in the UK, and the only study to value rural trees (Rogers and Evans 2015) used a general US externality value of £0.528 per m^3. This is a source of inaccuracy, but as the impact of surface water runoff is location specific, it would be impossible to produce an accurate value without detailed site-specific hydrological modelling. It should also be noted that the avoided runoff value only assesses drainage and water treatment costs and does not include the potential costs of flooding.

The value of avoided runoff is the lowest of the three main ecosystem services assessed by i-Tree Eco in the UK, ranging from £0.24 per tree in the Sid Valley to £1.26 in Wrexham for the 6 urban studies for which a value has been calculated. The value for the rural roadside study was even lower at only £0.13 per tree, but as explained above this was based on a lower cost per unit of water. The values obtained from the international studies were generally considerably higher, ranging from £0.84 in Davis, USA to £39.31 in Lisbon, Portugal (Table 6). It appears that trees in the international studies are intercepting much greater volumes of water, 3.2-11.3 m^3 per tree, compared to 0.25-0.76 m^3 per tree for the UK studies. This difference may be driven by climate, as all the international studies were from hotter climates than the UK, but tree species and size may also play a part. The study in Lisbon (Soares et al. 2011) appears to be particularly high as it explicitly assesses the cost of flood risk management, which is calculated at a cost of £8.60 ($10.49) per m^3.

5.2.4 Energy saving

Trees can save energy by reducing the amount of money spent on cooling buildings in the summer, through shading, and heating in the winter, through shelter from the prevailing wind. Once energy savings have been calculated, these can be monetised fairly readily. Energy saving is a major benefit in the international studies examined here, with benefits ranging from £2.75 per tree per year in Los Angeles to £52.46 in Adelaide, and is one of the larger benefits of urban trees in the hotter climates represented by these studies. On the other hand, the impact of urban trees on energy saving in the UK was minimal in the three cities in which it has been studied (London, Bridgend, and the Tawe catchment which included Cardiff). Benefits in these three areas were calculated to be £0.03, -£0.02, and £0.27 per tree respectively. A negative value indicated that there was a net cost of trees in Bridgend, arising due to a slight increase in heating required in the winter due to shading. In all three cases, urban trees were found to save energy in the summer, but in London and Bridgend these savings were mostly or completely offset by increased heating requirements in the winter. It was noted that trees can be managed to reduce their negative impact in the winter, by for example raising crown heights and carefully positioning new trees with respect to buildings. In the UK most domestic houses do not have air conditioning units, hence the summer savings are much less than in the USA and other hot countries where they are prevalent.

5.2.5 Amenity value and property prices

The amenity value of a tree is usually calculated in the UK using the CAVAT method (Section 5.1.2). The CAVAT value is a total asset value, rather than an annual value. Therefore, to enable comparison with the other values reported above, we converted this into an annual value by dividing by the standard UK Government annuity rate over 50 years. This assumes that the overall value of the tree stock will remain approximately similar over that time period, although there will inevitably be turnover of stock and change in the value of individual trees.

The annual amenity value was very high, ranging from £60.20 per tree for the Tawe catchment (Swansea area) to £201.04 for London (Table 5) for the five urban studies for which a value is reported. This is much higher than all the other values reported above. The London value is likely to be highest due to the high human population density and presence of a large number of large and iconic trees. Unsurprisingly, amenity value for the rural roadside in SW England was considerably lower than the urban areas at £5.19, although this was still larger than the other services.

The amenity or aesthetic value of trees can also be captured to some extent by comparing differences in sales prices of properties with and without trees, which can be revealed through hedonic pricing. Many studies have examined the impact of general green space cover or woodland views on house prices, but fewer have examined the role of individual trees, and the majority of these have come from North America. Where studies have been carried out, however, the consensus is that the effect of trees is to increase house prices. For example, Anderson and Cordell (1988) found that trees in Athens, Georgia added 3.5-4.5% to house sales prices (each tree adding 0.88% on average), Des Rosiers et al. (2002) recorded a 7.7% increase for trees and hedges in Quebec, Canada, and Donovan and Butry (2010) found that street trees in Portland added 3.0% to sales prices. Donovan and Butry (2010) also found that street trees reduced the time that a house was on the market by 1.7 days. Note, however, that some studies reported that if tree cover increased too much, it had a negative effect on house prices (e.g. Des Rosiers et al. 2002).

All the international studies on the economic benefits of trees shown in Table 6 calculated the benefits of trees on property prices using the same method. This was based on a single study by Anderson and Cordell (1988) who reported that each tree added 0.88% to the value of a property. The benefits of trees have therefore been valued as 0.88% of the median value of residential properties in each study area, with some adjustments made to account for property type. Values of £17 (Bismarck; McPherson et al. 2005) to £119 (Lisbon; Soares et al. 2011) per tree were reported (Table 6). Care should be taken when comparing with the UK amenity values calculated using CAVAT, as the methods are totally different. However, it's interesting to note that the values are fairly similar, and that the values for property prices and amenity value are larger, and in most cases considerably larger, than for the other services.

5.2.8 Other valuations

There is anecdotal evidence to suggest that trees create a more attractive environment that helps to attract businesses and customers. There is a lot of evidence regarding the economic benefits of green space in general for business, but little evidence specifically relating to trees. However, Burden (2006) reported that businesses on streets with trees showed a 20% higher income compared to those without.

Roy et al. (2012) carried out a systematic quantitative review of urban tree benefits and found 28 papers that examined economic benefits, all but one of which demonstrated an economic benefit from urban trees. Increasing property values was the most common benefit reported, but other benefits demonstrated included reduced expenditure on air pollution removal, reduced expenditure on storm water infrastructure, saved investment in new power supplies, reduced heating and cooling costs, increased property taxes, and increased tourism revenues.

Table 5: Monetary values of a range of ecosystem services provided by trees from 8 urban and 1 rural roadside locations. Values shown are the total monetary value for each ecosystem service across the study area, as well as mean value per hectare and mean value per tree. See Table 2 for data sources.

	Torbay	Edinburgh	Wrexham	Glasgow	Sid Valley	London	Bridgend	Tawe catchment	Highways Agency 1
Pollution removal:									
Total value per year	£281,495	£2,300,000	£700,000	£2,750,000	£720,000	£126,100,000	£325,991	£715,473	£611,000
Annual value per ha	£44.05	£200.44	£182.67	£155.87	£154.67	£790.74	£73.42	£102.28	£628.60
Annual value per tree	£0.34	£3.61	£1.92	£1.38	£1.78	£14.97	£0.74	£1.35	£2.02
Net carbon sequestration:									
*Total value 2016	£767,617	£1,091,542	£307,278	£1,849,680	£610,394	£15,152,116	£480,686	£693,630	£457,796
Annual value per ha	£120.11	£95.12	£80.19	£104.84	£131.13	£95.02	£108.26	£99.16	£470.98
Annual value per tree	£0.94	£1.71	£0.84	£0.92	£1.51	£1.80	£1.09	£1.31	£1.51
Avoided runoff:									
Total value per year	-	-	£460,000	£1,100,000	£96,400	£2,800,000	£163,760	£333,865	£40,020
Annual value per ha	-	-	£120.04	£62.35	£20.71	£17.56	£36.88	£47.73	£41.17
Annual value per tree	-	-	£1.26	£0.55	£0.24	£0.33	£0.37	£0.63	£0.13
Amenity value:									
Total asset value (CAVAT)	-	-	£1,400M	£4,000M	-	£43,300M	£686M	£816M	£40.2M
Asset value per tree (CAVAT)	-	-	£3,846	£2,000	-	£5,142	£1,563	£1,540	£133
**Annual value per tree	-	-	£150.38	£78.20	-	£201.04	£61.10	£60.20	£5.19
Replacement cost:									
Total	£280M	£382M	£900M	£4,600M	£170M	£6,120M	£142M	£234M	£91.4M
Per tree	£342	£599	£2,473	£2,300	£420	£727	£323	£442	£302

* The method used to value carbon sequestration has changed over the years, with earlier studies using a very low carbon price. To enable a more accurate comparison we re-calculated all carbon values using the 2016 UK Government non-traded carbon price (£63 tCO_2e; DECC 2015). ** CAVAT value is a total asset value. We converted this into an annual value for comparison with the other ecosystem services by dividing by the standard UK Government annuity rate over 50 years. This assumes that the overall value of the tree stock will remain approximately similar over that time period, although there will be turnover of stock and change in the value of individual trees.

Table 6: Overall economic benefits of trees, compiled from 9 UK and 5 international studies.

Note that prices from all international studies have been converted from US dollars to UK pounds using the January 2017 exchange rate (£1 = $1.22).

	UK urban areas	UK rural roadside	Soares et al. 2011	McPherson et al. 2011	McPherson et al. 2005	Maco & McPherson 2003	Killicoat et al. 2002
Location of study	8 UK towns and cities	SW England	Lisbon, Portugal	Los Angeles, USA	5 US cities	Davis, USA	Adelaide, Australia
Notes	Medians shown. No. of studies in parentheses	Only 1 study		Low mortality estimate	Mean of the 5 cities	Public street trees only	
Annual values per tree:							
Pollution removal	£1.58 (8)	£2.02	£4.44	£1.95	£0.40	£9.46	£28.28
Carbon sequestration	£1.20 (8)	£1.51	£0.27	£0.20	£1.06	£3.52	£0.82
Avoided runoff	£0.44 (6)	£0.13	£39.31	£3.58	£8.49	£0.84	£5.33
Energy saving	£0.03 (3)	-	£5.06	£2.75	£6.55	£9.44	£52.46
Amenity (CAVAT)	£78.20 (5)	£5.19	-	-	-	-	-
Property value	-	-	£118.87	£37.20	£30.29	£35.03	£53.28
Total annual value	**£81.45**	**£8.85**	**£167.95**	**£45.68**	**£46.81**	**£58.30**	**£140.16**
Asset values per tree:							
Replacement cost	£520 (8)	£302					
CAVAT (amenity value)	£2,000 (5)	£133					

5.3 Value for money

The total annual benefit per tree for UK urban areas is £81.45 taking the median values from the eight available studies (Table 6). This is comparable to the international studies, where total value ranged from £45.68 to £167.95 per tree per year. Amenity value accounts for 96% of the total value in the UK studies, whilst property value was almost as high in the international studies, accounting for more than 60% of the total value in all except one study. The only study to examine UK rural roadsides gave an overall value pf £8.85 per tree, excluding screening value. This is much lower due to the reduced amenity value of these trees compared to urban trees.

If the annual values are converted into a total asset value, each tree is worth an average of £2,083 over 50 years, with trees in London the most valuable at £5,580. But note that there will be considerable turnover over the 50 years, with many trees dying and being replaced, with surviving trees likely to increase in value considerably over that time. The asset value for a rural roadside tree is £226 on average.

When all the trees in an urban area are combined, the overall value is considerable, with annual values ranging from £27.8M for Bridgend up to £1,837M for London, and overall asset values from £711M to £47 billion.

5.3.1 Planting and maintenance costs

On average the publicly owned street trees in London cost £110 for planting and £21 for annual maintenance in 2011 (London Assembly 2011). Other sources have estimated planting costs of £15-400 per tree, with costs decreasing with the number of trees planted (Westcountry Rivers Trust 2016). Note, however, that if new tree pits are required in areas of sealed surface then these costs will be considerably higher. Estimates from the USA suggest that maintenance costs range from $20 (£16.40) for a publicly owned small tree up to $40 (£32.80) for a privately owned large deciduous tree (McPherson et al. 2007). In a separate study, total costs spent on all tree related activities averaged across 5 cities was £24.13 (McPherson et al. 2005), and in Lisbon costs were estimated at £37.41 (Soares et al. 2011).

It has been suggested that an asset should have between 0.5% and 1.5% of its total asset value dedicated to its upkeep for that asset to be kept in a good state of repair and for it not to degrade and become a financial liability (Forestry Commission 2013). The annual maintenance cost for London represents less than 0.4 % of the average asset value for a tree in London or 1.0% of the median asset value across all urban studies. It has also been noted that trees are cheaper to maintain than amenity grassland and trees in managed green space are likely to be cheaper to manage than street trees.

There is little information on the maintenance costs of rural roadside trees, although it may be possible to obtain this from individual councils and the Highways Authority. It is highly likely, however, that it is considerably cheaper than the costs of maintaining urban street trees. In the rural roadside study in SW England, Rogers and Evans (2015) state that the costs of maintenance were less than 1% of the benefits obtained from these trees.

5.3.2 Overall value

Taking planting and maintenance costs into account, it is clear that urban trees deliver considerably more in benefits than they cost. Although costs were not collected in the UK studies described above, it is likely that overall annual costs including both planting and maintenance will be around £25 per tree, with £81 of benefits delivered. This gives a net benefit of approximately £56 per tree per year and a cost benefit ratio of 1:3.2. In comparison, the average net benefit of urban trees across 5 cities in the US was £22.67 with a benefit ratio of 1.9 (McPherson et al. 2005), and in Lisbon the net benefit was £130.54 at 4.48 benefit to costs (Soares et al. 2011). McPherson et al. (2007) estimate that in the northeast USA net annual benefits range from $5 (£4.10) for a small garden tree to $113 (£92.62) for a large deciduous street tree.

The benefits received from a rural roadside tree are considerably less than for an urban tree, at £8.85 per tree, but it is likely that annual maintenance costs will be much lower than this (e.g. Rogers and Evans 2015), hence rural roadside trees almost certainly deliver a net benefit as well. TOWs in rural areas away from roads have received the least attention of all and there are no studies of their economic benefits. It is likely that the benefits monetised in the urban and roadside studies will be less relevant in countryside locations, as air pollution and amenity values will generally be low, except in a few settings. However, these trees are likely to deliver a range of other benefits, especially to agriculture, and are also likely to have extremely low maintenance costs. It is not currently possible to place a generic monetary value on these benefits.

Economic valuations of TOWs base their estimates on a small number of ecosystem services. There are many more ecosystem services delivered by TOWs (Section 2), which are either not possible to value or can only be valued with detailed site-specific studies. This means that any economic assessment will only give a partial estimation of the total economic value of TOWs (and other aspects of natural capital), hence their true value will be considerably higher than these studies show.

6. Conclusions and recommendations

Trees outside woods (TOWs) provide a wide range of benefits to society. However, these are not always recognised and valued, whereas the costs of damage and the nuisance that trees can cause are widely reported (Mullaney et al. 2015). Hence TOWs can be undervalued and underappreciated by some in society, especially those who bear the costs of their maintenance. This is in contrast to woodlands, which often provide direct economic benefits through timber and as a location for recreational activities, and are more easily recognisable for the many other benefits that they provide. If TOWs are not valued, but are merely seen as a cost, then they start to be viewed as a liability rather than an asset and will gradually be removed and not replaced (Mullaney et al. 2015). With the increasing prevalence of tree diseases such as ash dieback, the risk is that local authorities and other responsible parties will proactively fell large numbers of trees at the first sign of disease and not replant, in an effort to reduce risk and save costs. Highlighting the benefits of trees and placing a monetary value on at least some of these benefits is thus becoming increasingly important. It helps to reframe the agenda, highlighting that TOWs do have multiple benefits. Where benefits can be given a monetary value, these can also be compared to maintenance and planting costs to directly justify tree budgets. Studies that have calculated the economic costs and benefits of trees have shown that the benefits tend to outweigh the costs, with the majority of the benefit coming from amenity value. These studies are only able to assess a few of the benefits (and disbenefits) provided by trees, hence it is likely that the true value of TOWs will be considerably higher.

The study of the impact of emerald ash borer on human mortality in the USA (Donovan et al. 2013) has particular resonance for the UK. Ash trees in the UK are already under serious threat from ash dieback and the expected arrival of the emerald ash borer will compound the problem. Ash is extremely common in the UK and the wholesale loss of ash trees, whether directly through disease or indirectly through land managers proactively felling trees deemed to be at risk, will reduce tree cover substantially. In the USA, a smaller decrease in tree cover has been linked with a large increase in human mortality, possibly linked to the loss of the air pollution amelioration function that these trees perform. This provides a warning that tree managers should not be too hasty to remove ash trees, and when unavoidable, should replace trees with alternative species. It also shows the need for more research and monitoring in this area where there are still many knowledge gaps.

Trees can be highly emotive. When trees are under threat of felling, especially trees in public spaces, passions can run high, as evidenced most recently in the ongoing disputes occurring in Sheffield (Guardian 2016, 2017). This shows that some people can place huge value and emotional attachment on trees, regardless of economic arguments. Economic arguments are, perhaps, more important for local authorities and others responsible for the publicly-owned trees. Homeowners, however, can be more dispassionate about trees on their own property. When a tree is causing or has the potential to cause damage or a nuisance, then many homeowners are quick to fell the offending tree.

The majority of studies on TOWs, and particularly the economic studies, have focussed on urban trees. This is perhaps not surprising as urban trees benefit far more people than rural trees, and are also the most expensive to maintain. Where evidence is available, it appears that rural roadside trees and trees in the wider countryside provide a number of benefits that outweigh costs, although this is an area that requires more research.

The perceived role of TOWs is starting to change, especially in urban areas. Whereas such trees have traditionally been seen to be primarily about aesthetics and ornamentation, they are now starting to be recognised for the multiple benefits that they provide to society and the environment (Silvera Seamans 2013). This is also true for rural roadside trees and trees in the wider countryside, although the benefits provided by these latter trees are somewhat different. It is important that a holistic approach is taken when examining TOWs, so that the full range of services and disservices can be assessed.

TOWs are clearly not uniform in the benefits that they provide, with very different values associated with individual trees, dependent upon the location and on the characteristics of the tree. Damage, nuisance and general disbenefits associated with trees are also highly variable for the same reasons. As Salmond et al. (2016) argue, current understanding of the impact of trees has been limited by approaches that consider only single services or impacts, without considering wider synergistic impacts of trees on the environment. This can lead to poor decision making and to simple solutions being applied across a wide area, whereas different benefits, impacts and trade-offs may occur in different settings. Understanding the full range of benefits and disbenefits provided by TOWs and how these vary with location and tree characteristics is thus a key step in achieving more sustainable management of these assets.

6.1 Recommendations

The following recommendations are proposed:

- Everyone associated with the planning and management of trees outside woods (TOWs) should be encouraged to consider the multiple benefits provided by trees.
- More effort should be made to plant the right tree species in the right location to gain maximum benefits and reduce the chance of disbenefits. This is particularly relevant in new developments and other new planting schemes, but more widespread promotion of guidelines (perhaps written and promoted by the Woodland Trust) would be beneficial to all.
- When it is necessary to fell trees, replanting should be strongly encouraged and promoted. This is particularly relevant in regard to ash dieback, as it is likely that large numbers of trees (especially roadside and urban trees) will be felled over the coming few years. It is really important that these trees and the services that they provide are replaced.
- Encouraging greater planting of trees in general, to provide many of the benefits described in this document. Street trees in particular should be promoted through working with local authorities, developers and other relevant parties, and integrating green infrastructure into new developments should be further encouraged.
- Further research and studies are required, especially with regard to:
  - The economic value of TOWs outside of urban areas.
  - The impact of different ash removal strategies on ecosystem services. This could be assessed by considering different scenarios, for example comparing the impact of replacing felled trees with non-replacement, and comparing removing all ash trees on first detection of disease in an area with a less severe approach.
  - The delivery of ecosystem services by TOWs at a landscape scale and in relation to other landscape elements.
  - Integrating with remote sensing research, which could potentially be used to identify different tree species and tree health from satellite or aerial imagery, and then combined with ecosystem services assessment.
  - Monitoring the impact of the spread of ash dieback on ecosystem services and health. This provides the opportunity to carry out a natural experiment on the impact of a potentially major change to our landscape on people.
  - Research to determine the economic value of more of the services provided by trees.

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