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Urban air quality

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Whilst air quality in the UK has improved in recent decades, concentrations of some pollutants, such as oxides of nitrogen, are now leveling off and there remain serious health issues relating to air pollution, particularly in towns and cities. Air quality is often listed as one of the potential benefits of increasing tree cover in urban areas, but few urban greening projects appear to take into account how air quality goals can best be achieved.

The main pollutants of concern are particulate matter (PM), oxides of nitrogen, and ground-level ozone. Road transport and the burning of fossil fuels, for instance in large fuel-burning plants such as power stations, are the biggest sources of these pollutants.

According to the Department of the Environment, Food and Rural Affairs, the economic cost from the impacts of air pollution in the UK is estimated at £9-19 billion every year. Amongst the worst affected are poorer areas, which are often in urban areas, close to busy roads and inadequately served by green space.

Estimates indicate that air pollution reduces life expectancy in the UK by seven to eight months, according to the Environmental Audit Committee (2010). Air pollution causes irritation of the lungs and can worsen lung conditions, including asthma. Poor air quality also affects people with heart conditions, especially when combined with high summer temperatures.

Increasing tree cover in urban areas can help mitigate the 'urban heat island effect'. The urban heat island occurs in towns and cities because the buildings, concrete and other hard surfaces such as roads absorb heat during the day and release it at night. The resultant effects can be dramatic; on some days there is a difference of as much as 10°C between city centres and the surrounding areas.

The impact on health of urban heat islands is two-fold. Firstly, higher temperatures can increase ground-level ozone, exacerbating the symptoms of chronic lung conditions. Secondly, prolonged high temperature can bring on heart or respiratory failure or dehydration, particularly amongst the elderly, very young or chronically ill (Bhattachary 2003).

The heat island problem is exacerbated by a lack of green space in cities. Green space, and trees in particular, provide both direct cooling from shade and reduce the ambient temperature through the cooling effect of evaporation of water from the soil and through plant leaves.

Although some trees produce pollen which can affect a proportion of hay fever sufferers, the overall benefits of trees to air quality respiratory health are overwhelmingly positive (Hewitt 2005). According to the British Lung Foundation one in every seven people in the UK is affected by lung disease — almost 8 million people (British Lung Foundation, undated).

The importance of trees and urban green space

There is evidence that urban trees remove large amounts of air pollution and improve urban air quality (Nowak *et al* 2006). Columbia University researchers found asthma rates among children aged four and five was significantly lower in areas with more street trees (Lovasi *et al* 2008). The UK has one of the world's highest rates of childhood asthma, with about 15 per cent of children affected and a higher prevalence in lower socio economic groups in urban areas (Townshend 2007).

Research in recent years has begun to identify how urban greening, and tree planting in particular, might be tailored to achieve air quality goals whilst still fulfilling many of the other beneficial functions of urban green space. Not all vegetation positioning yields an equal pollutant removal potential. Local airflows and pollutant concentrations will significantly affect the efficiency with which vegetation can remove pollution (MacKenzie et al., 2011).

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Urban vegetation is often concentrated in parks or private gardens, where pollutant concentrations are likely to be relatively low. Whilst this vegetation has many other benefits (reducing heat island effect, mitigating surface water run-off, supporting biodiversity etc), vegetation near polluted areas will scrub the air of pollutants more effectively.

Where improving air quality outcomes is the primary objective, planting in areas of high pollution, for instance 'hotspots' such as traffic junctions and traffic lights, will yield proportionately greater rates of pollutant removal (Mitchell and Maher, 2009). But care must be taken not to reduce dispersion from local pollutant sources such as traffic, which may lead to local concentration increases, despite the overall reduction (see the case of street canyons, below).

Tree-for-tree, single trees and trees on the edge of woodland collect particles more efficiently than those in the centre of a woodland (Branford et al., 2004; McDonald et al., 2007). This deposition 'edge' effect can be used for screening of high pollution sources. Dense trees in conjunction with understory plants to leeward of air pollution sources can maximise pollutant scrubbing by plants.

Greatest benefits could be achieved by two or three rows of trees with a relatively high planting density (Jim and Chen, 2008). Screening by a single tree alone has been estimated to reduce PM concentration by 15-20 % immediately behind the tree (Bealey et al., 2007; Mitchell and Maher, 2009).

The problem of street canyons

The zone between rows of buildings along a street is often called a 'street canyon.' Street canyons can trap pollutants because the air in the canyon exchanges only slowly with the air above. Concentrations of pollutants emitted at the bottom of the canyon are highest at the base of the windward wall (Gromke and Ruck, 2009; Buccolieri et al., 2009). Where the prevailing wind is consistently from one direction, there may be an advantage to planting trees and other vegetation near the windward wall where it can capture pollutants.

The rate of exchange of air between canyon and the overlying atmosphere decreases as the height-to-width ratio of the canyon increases — i.e., is reduced in narrow streets with tall buildings (e.g. Oke, 1988). Where the street canyon contains a pollutant source this reduced-exchange effect can

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lead to greatly increased pollutant concentrations at street-level ; where people are most likely to be exposed (DePaul and Sheih, 1986).

Although vegetation in street canyons can remove pollutants, recent research suggests that avenues of street trees within the worse polluted street canyons might reduce mixing and dispersion and hence exacerbate air quality problems at the street-level (Gromke and Ruck, 2009; Buccolieri et al., 2009). Whilst these studies do not account for the effects of deposition to vegetation, they highlight that there may be a balance to be struck, and that the greatest benefits of street trees may be in the less polluted canyons.

Factors such as crown porosity are also important; denser crowns will have a greater trapping effect (Gromke and Ruck, 2009), but are also likely to have greater pollutant deposition.

Species choice

Species choice has a large influence on the potential for pollutant scrubbing by trees and other vegetation.

Evergreen species contribute to pollutant scrubbing year-round; deciduous species are limited to stem deposition only in winter. The contribution of stems to particulate deposition can be substantial, dependent on species (Freer-Smith et al., 2004). When in leaf, broadleaf species may also be more efficient than needle-leaf species, due to the higher leaf surface area of broadleaf trees (Jim and Chen, 2008).

The differences between tree species play an important role in estimating particulate capture; leaves with complex shapes, large circumference-to-area ratios, waxy cuticles or fine hairs on their surfaces collect particles more efficiently (Tiwary et al., 2009). In particular leaf surfaces appear to be important, with ridged hairy leaves giving the highest particle deposition (Mitchell et al., 2010).

Plants with low 'stomatal conductance' – the rate at which water vapour and gases pass through the openings on the leaf surface – can better tolerate high levels of gaseous pollutants (although they will also be less efficient at removing them from the atmosphere) (Kozlowski, 2003). Therefore, in areas of very high pollution, such plants may be selected due to their increased vitality under these conditions. However, since around a third to two thirds of ozone deposition (Fowler et al., 2009) and nearly all particulate deposition(most associated with detrimental health effects), is 'non-stomatal', i.e. on the leaf surface, the potential of any tree to improve air quality remains high.

Biogenic volatile organic compounds (BVOCs) emitted by trees can cause increases in ozone pollution, acting contrary to the pollution-scrubbing effect. Not all species emit BVOCs at the same rate, therefore selection of low BVOC emitting species where possible can decrease the risk of high-ozone episodes.

In an attempt to balance the pollution-scrubbing and BVOC emission effects of trees, an urban tree air quality score (UTAQS) has been developed (Donovan et al, 2005). The UTAQS classifies trees by weighing up their ability to reduce and to exacerbate air pollution, with a higher score indicating a better species choice for air quality purposes. Figure I shows the classification of 30 of the most common UK urban tree species using UTAQS.

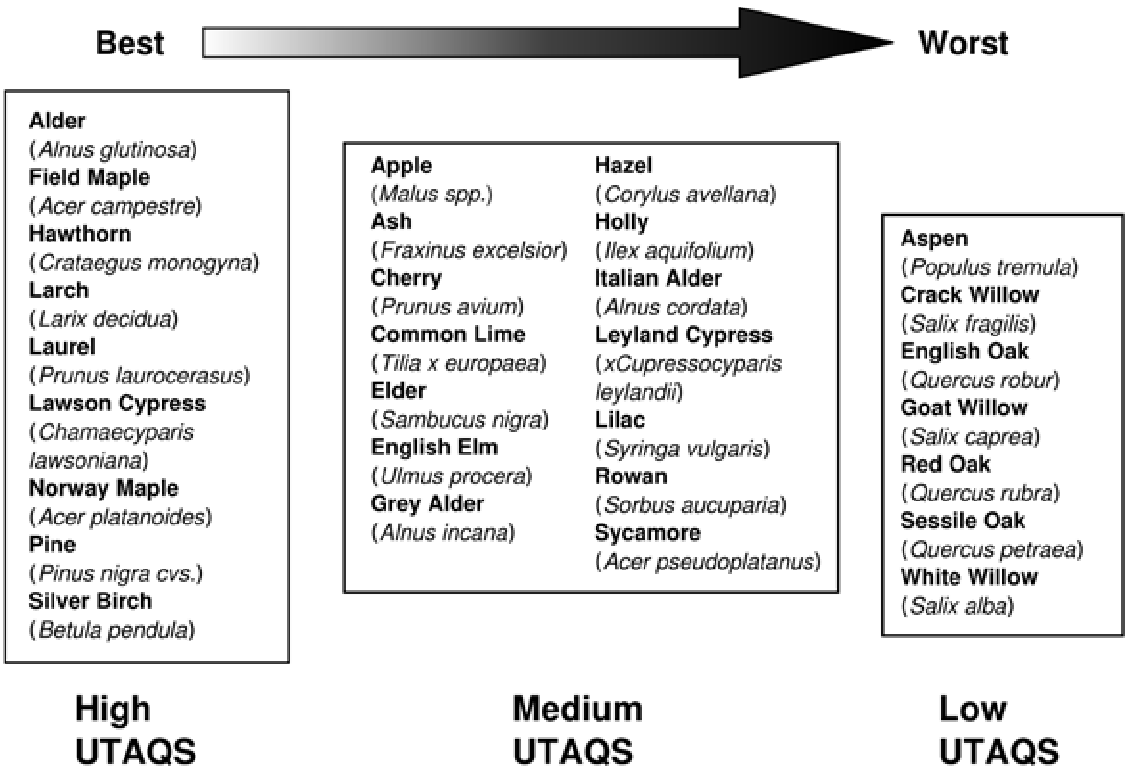

Figure I. Urban tree air quality score (UTAQS) classification for 30 tree species common in the West Midlands metropolitan area, UK.

 More details from UTAQS can be found at http://www.es.lancs.ac.uk/people/cnh/docs/UrbanTrees.htm

The size of the tree also affects its ability to capture particles. Trees with a large leaf area can remove many times more particulate pollution per year than small ones (60-70 times in one study; Nowak, 1994), although younger trees tend to be disproportionally effective (relative to their leaf area) due to their greater foliar densities (Beckett et al., 2000).

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The importance of tree maintenance

Tree species selection and positioning are critical initial steps in designing green infrastructure to improve air quality. However, like any infrastructure, vegetation will act more effectively to remove air pollutants if it is properly maintained; the resilience of sustainability solutions like tree planting, in the face of an uncertain future, is often overlooked (Pugh et al., 2012; Boyko et al., 2011). Careful maintenance to ensure plant health will increase the leaf area and increase the pollution-scrubbing effect of plants (Jim and Chen, 2008).

Changing the way we live

Although much can be done to improve the choice and siting of trees and other vegetation for air quality, the greatest benefits will be achieved if people can be close to, or even within, green infrastructure when moving around towns and cities. For instance, the largest decreases in particulates due to uptake by vegetation were in the green spaces themselves (Tiwary et al, 2009). The health benefits to people are greatest, therefore, if pedestrians use parks and other green spaces rather than the pavements alongside busy roads. Geographical information systems and mobile phone applications can now be used to plot routes of least air pollutant exposure, taking advantage of vegetated areas (Davies and Whyatt 2009). Such methods may also be useful in planning large-scale greening, or to optimise routes to and from major businesses, schools or shopping areas.

Planning for air quality

Air quality remains a persistent problem in many towns and cities, with consequent costs to public health and the environment. Careful planning of green infrastructure can ensure that trees and other vegetation are well sited to maximise the opportunities for improving air quality.

Careful selection of tree species can also help to ensure that the positive impacts are greatest and any negative impacts minimised. However the large scale planting of almost all tree species will have a positive effect on air quality (Donovan et al., 2005).

Careful, but not necessarily onerous, maintenance of tree cover in urban areas will ensure that trees thrive and continue to remove pollutants.

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