Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

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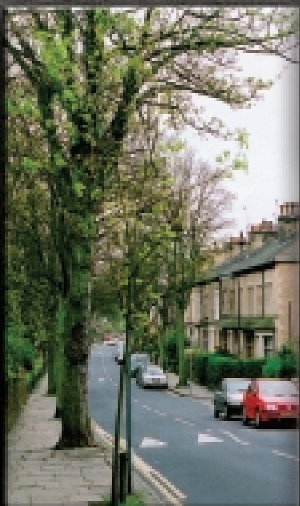
Trees & Sustainable Urban Air Quality

Using Trees to Improve Air Quality in Cities

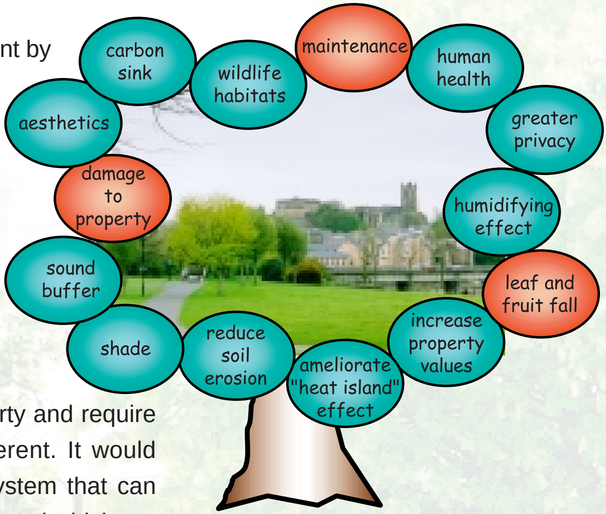


Trees in the urban environment

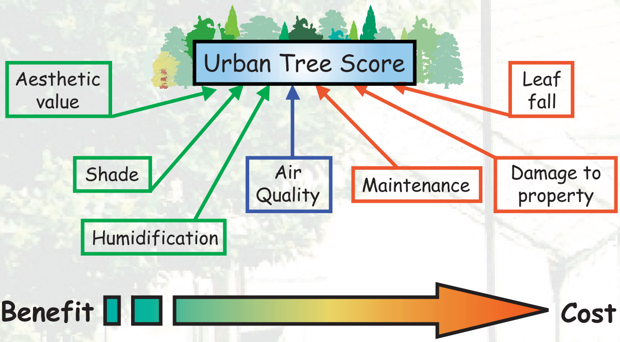
You don't have to be a tree surgeon to appreciate the value of urban trees. They affect our lives in more ways than we realise. Did you know that patients recover more quickly from major surgery if they can see trees from their hospital bed?

Trees can improve the environment by

- benefitting human health
- affecting air quality
- providing shade and humidity
- having aesthetic qualities
- increasing biodiversity
- creating a sense of community
- increasing property prices



But they can also damage property and require maintenance. Trees are all different. It would therefore be useful to have a system that can show which tree species are best and which are bad for the urban environment.



People plant trees for so many reasons that it is not possible to produce a scoring system that considers all the factors. Here, we focus on the ability of urban trees to improve air quality. Some trees are better than others at doing this.

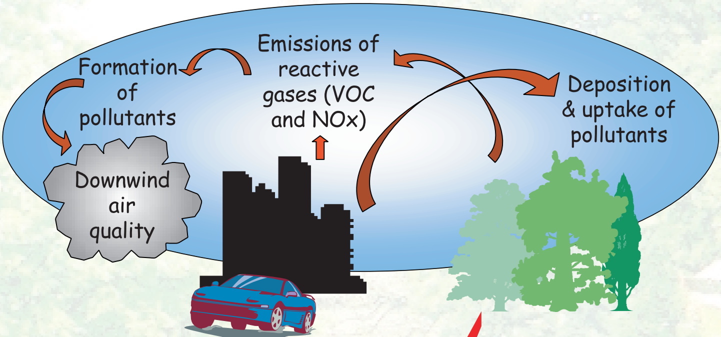
To do this, we have developed an **U**rban **T**ree **A**ir **Q**uality **S**core (UTAQS), using the West Midlands as a typical urban region in Great Britain. This pamphlet describes

- the way trees affect air quality
- the system we have developed to test the ability of trees to influence air quality
- the final tree ranking or UTAQS.

We hope urban planners and policy makers will consider the effects trees can have on air quality and that UTAQS will be a useful tool for them.

Urban trees and air quality

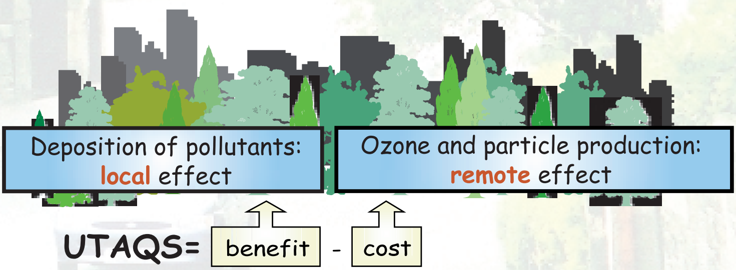
Most people assume that trees only benefit air quality. In fact, some tree species can have a negative effect and actually help to form pollutants in the atmosphere.



Trees can emit gases known as volatile organic compounds (VOCs). These are what you can smell in forests. VOCs, in combination with the man-made oxides of nitrogen (NOx), can contribute to the production of other pollutants, especially ozone and particles, which damage human health when in the lower atmosphere.

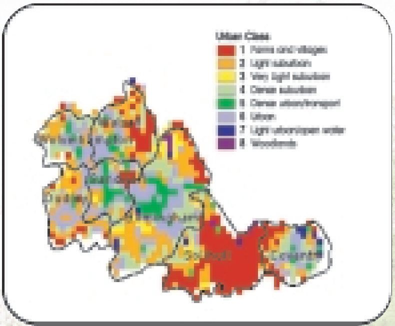
Trees can remove pollutants, especially ozone, nitrogen dioxide, and particles) from the air which makes the atmosphere cleaner. Trees also remove carbon dioxide from the atmosphere but we treat this separately on page 9. Carbon dioxide is a greenhouse gas which is having effects on the earth's climate.

The removal of pollutants by trees is a local effect, whereas the formation of pollutants from compounds emitted by trees happens downwind of the trees themselves. To generate an Urban Tree Air Quality Score, we need to weigh the local benefits against the remote costs. In order to do this, we have used a case study, and this is described in the rest of the brochure.



A case study - trees in the West Midlands

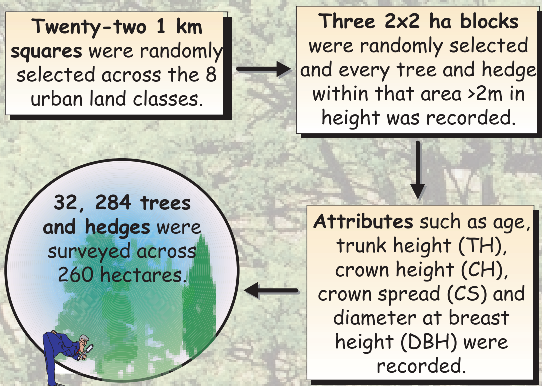
1 Land classification



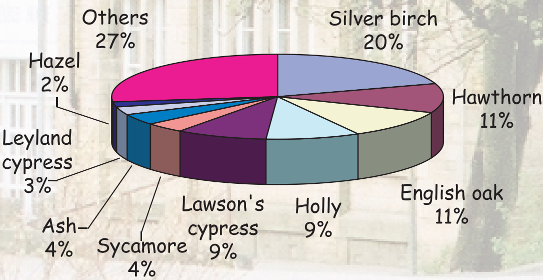
The West Midlands urban area is 900 km^2 in size. We divided it into eight different urban land classes using maps of land cover in the area. Each km^2 belongs to one of the eight classes as shown on the left. The descriptions of the land classes give a general idea of the dominant land cover in the class, but don't mean that the whole km^2 is covered with that land cover type. For example, on average only 42% of woodland (land class 8) is actually covered with woodland.

2 Tree Survey

We surveyed 32,000 randomly chosen trees in the West Midlands in 1999, recording tree age, condition, height and trunk diameter. The survey process is described on the right.



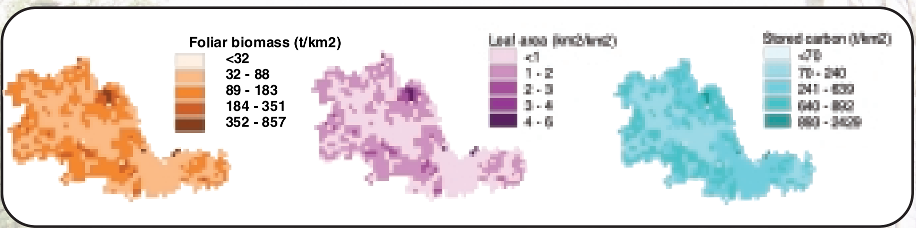
Using these results, we were able to predict the tree population of each urban land class and hence the species composition and size of the whole West Midlands tree population. The pie chart shows the composition of species in the West Midlands and the table shows the number of trees in each land class and in the West Midlands conurbation as a whole.



Urban land class	Tree count (million trees)
1 Farms and villages	1.4
2 Light suburban	2.1
3 Very light suburban	0.8
4 Dense suburban	1.2
5 Dense urban/transport	0.7
6 Urban	1.5
7 Light urban/open water	0.03
8 Woodloand	0.3
West Midlands	8.1

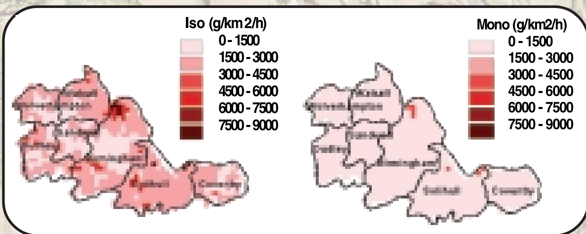
3 Calculating foliar biomass, leaf area and stored carbon

We calculated leaf area, foliar biomass and stored carbon from the tree size data collected in the West Midlands survey for each land class and scaled the leaf attributes monthly to account for the growth cycle of deciduous trees. These maps show the distributions of these attributes in the West Midlands during the month of August.

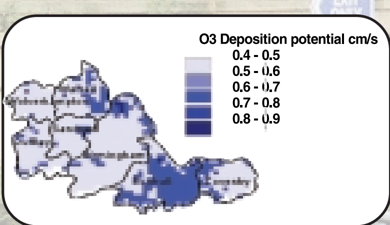


4 Estimating emission potential (EP)

The emissions of volatile organic compounds that would take place at a temperature of 30°C in bright sunlight were calculated by multiplying the foliar biomass of each tree species by the relevent emission potential for each species, found at www.es.lancs.ac.uk/cnhgroup/iso-emissions.pdf. Isoprene and the monoterpene family are the most important naturally emitted VOCs so the assignment was limited to these compounds. Summing the EPs for each land class gives the isoprene and monoterpene emission distributions shown here.



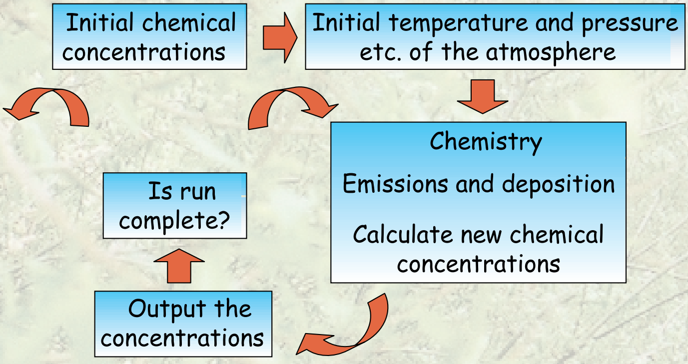
5 Estimating deposition potential (DP)



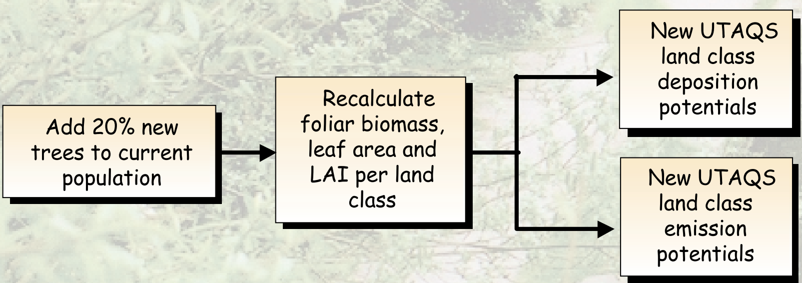
The proportions of grass, water, trees and built-up land in each land class are unique. Each surface has a unique capacity to capture chemical species (i.e. has a unique deposition potential). The DPs of five chemical compounds important to urban air quality (ozone, nitric oxide, nitrogen dioxide, nitric acid and carbon monoxide) were weighted in proportion to the land cover areas to generate land class DPs. This map shows the distribution of ozone DP in the West Midlands in August, the highest values being in the most vegetated areas.

Introducing our air quality modelling tool - CiTTyCAT

CiTTyCAT (the Cambridge Tropospheric Trajectory model of Chemistry and Transport) is a computer model that simulates the chemistry of the lowest part of the atmosphere by picking up emissions, performing chemical reactions and depositing some of the products of the reactions at the earth's surface. The diagram below shows the way CiTTyCAT works.



We used CiTTyCAT to simulate atmospheric chemistry over the current West Midlands tree population for a five-day period. This gives the model enough time for the chemistry to reach a steady daily cycle. We then tested the effects of planting different tree species on the air quality in the region. We selected the 30 most common tree species in the West Midlands, making up 90% of the total population, and added 20% more trees of each of the 30 species in turn to the existing population. We recalculated the biomass and leaf area of each land class for each new tree population, and then calculated new emission and deposition potentials.

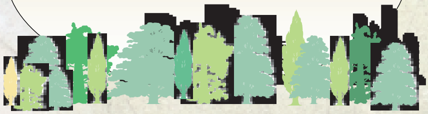


Finally, we ran the CiTTyCAT model for five days for each scenario and simulated air quality in the West Midlands with each of the different tree populations.

Urban tree air quality score

To rank the ability of the different tree species to affect air quality, we compared the concentrations of pollutants with each new tree population against those produced by the current one. We used a simple equation that takes into account the effect of changing tree species on pollutant formation and deposition, using ozone to represent all the relevant pollutants. The change in ozone concentration with each tree population was compared to the air quality standard for ozone* to estimate the significance of the change.

$$\text{UTAQS} = \frac{\text{Change in ozone concentration}}{\text{Air Quality Standard for ozone}}$$



We grouped the tree species according to their effect on air quality. They are grouped below as

- (green) trees that have the greatest capacity to improve air quality
- (yellow) trees that have a smaller capacity to improve air quality
- (red) trees that have the potential to worsen air quality.

Best → Worst

Ash, Common alder, Field maple, Larch, Norway maple, Scots pine, Silver birch

Apple	Holly
Cherry laurel	Italian alder
Common elm	Lawson cypress
Common lime	Leyland cypress
Elder	Lilac
Grey alder	Mountain ash
Hawthorn	Sycamore
Hazel	Wild cherry

Crack willow, English oak, Goat willow, Poplar, Red oak, Sessile oak, White willow

* The air quality standard for ozone in the UK is an 8-hour running mean of 50 ppb not to be exceeded on more than 10 days in one year. This is set as part of the government's National Air Quality Strategy. Details are found at www.aeat.co.uk/netcen/airqual/index.html.

Reducing airborne pollutants in urban areas with trees

1. The effects of land-type and 'edge' trees

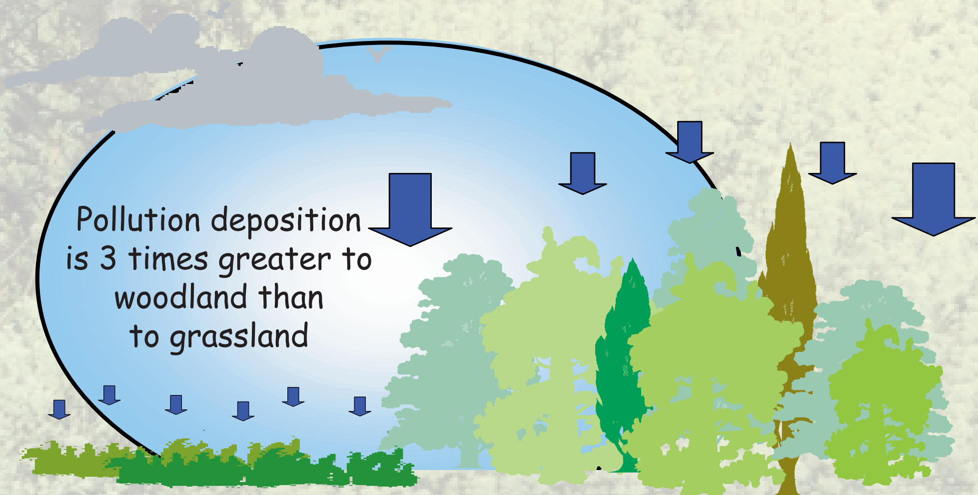
Trees are popularly believed to remove pollution from the atmosphere, removing both gases and particles. However, this idea has developed largely without careful measurements in real-life conditions to show

a) how large the effect is,
b) what processes control it and
c) how it might be exploited to improve air quality in urban areas.

To try to answer some of these questions, we measured the long-term (50 year) average deposition rate of airborne particles in urban air, such as those emitted by cars, on woodland, grassland and other short vegetation in the West Midlands conurbation. We did this by measuring the amount of naturally occurring radioactive compounds, found as particles in the atmosphere and soils, and then worked out the effect of trees on the rates of pollutant deposition.

The measurements show that

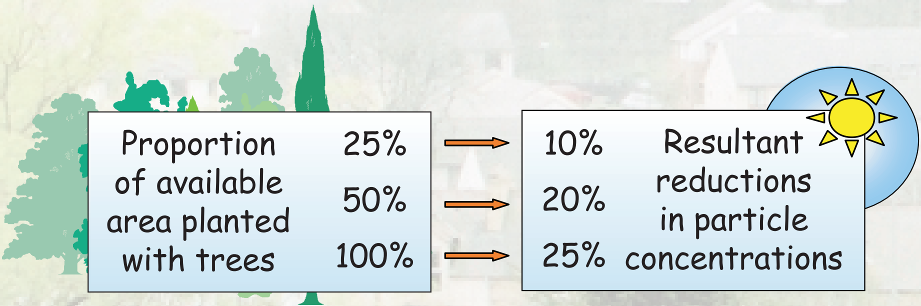
- mature, mixed woodland captures airborne particles at approximately three times the rate of grassland.
- trees on the edge of woodland are more effective at capturing airborne particles than the trees in the centre of the wood because they have larger leaf areas and are exposed to the wind.



2. How big is the effect?

We wanted to see the effect of various tree-planting schemes on the deposition of pollutants in the West Midlands so once again we used computer models that simulate atmospheric dispersion, transport and deposition.

In our tree survey of West Midlands, the area of land in each sampled hectare that was potentially available for tree-planting in the future was noted. This was used to caluate a land class average 'future planting potential' area, or FPP. We used the computer models to plant the FPP areas with 'instant' mature woodland, and then calculated the change in atmospheric concentration of PM10 (particles smaller than about 10 μm aerodynamic diameter)*. There were reductions in PM10 concentration with each scenario as shown below.



3. Human health

The main concern over airborne particles in cities is their effect on human health. A number of epidemiological studies have shown that a rise in PM10 concentrations of 10 μg m^{-3} (as a 24 hour average) is associated with an increase in mortality of 1%. The reduction in PM10 concentrations which would result from future tree planting would therefore be beneficial to human health. Quantifying this benefit is more difficult. However, using these health statistics and our predictions of the effects of tree planting on urban air quality, we estimate that doubling the number of trees in the West Midlands could reduce excess deaths due to particles in the air by up to 140 per year.

*We used PM10 because the Government's air quality standard for particles (50 μg m^{-3} as a 24 hour running mean) is based on this definition of size. These particles are believed to be small enough to reach the lungs.

Trees as carbon stores*

The total amount of carbon stored in the West Midlands tree population is equivalent to only 6% of the carbon dioxide emitted to the atmosphere from the West Midlands in a single year. In other words, all the trees in the West Midlands hold the equivalent of three weeks worth of emissions of CO_2 from the conurbation. Given the relatively small amount of carbon stored in the trees, we have not included carbon storage (sequestration) in our tree score. However, we have grouped the thirty species considered in our score into those that have high, medium or low growth rates, i.e. carbon sequestration rates, so that this factor can be considered when developing planting schemes.

High — Medium — Low

Crack willow	Apple	Italian alder	Common elm
Goat willow	Ash	Lilac	English oak
Larch	Cherry laurel	Mountain ash	Field maple
Lawson cypress	Common alder	Norway maple	Hazel
Leyland cypress	Common lime	Red oak	Holly
Poplar	Elder	Scots pine	Sessile oak
Silver birch	Grey alder	Sycamore	
White willow	Hawthorn	Wild cherry	

Which species have stored the most carbon so far?

We calculated the total amount of carbon stored by each tree species in the West Midlands. The top ten carbon storing species are shown on the right. By far the most important is the English oak (*Quercus robur*) with 36% of the total stored carbon because these trees are so big. However, it is slow growing so it has taken longer to accumulate it's carbon than some of the other species listed.

English name	Stored Carbon (kt)	% total
English oak	180	36.7
Austrian pine	35	7.1
Ash	27	5.5
Common lime	26	5.2
Silver birch	25	5.1
Sessile oak	22	4.4
Sycamore	16	3.3
Lombardy poplar	16	3.2
Horse chestnut	15	3.0
Common alder	11	2.3

*In all of this, we have not considered the effect trees have on the storage of carbon in soils (soils are a major store of carbon).

Summary

Trees are an integral part of the urban environment, affecting communities ecologically, socially, economically and physically and they benefit human health. We have looked at the effects of trees on air quality, trying to answer two questions:

1. **Which trees** are the best to plant to sustain and improve air quality?
2. **How big** is the effect trees have on urban air quality?

Which trees?

Trees that don't emit the most reactive volatile organic compounds (VOCs), but do have large leaf surface areas have the best effect on air quality. Scots pine, common alder, larch, Norway maple, field maple, ash and silver birch remove the most pollutants without contributing to the formation of new pollutants. Oaks, poplars and willows can have detrimental effects on air quality downwind, so care needs to be taken when planting these species in very large numbers. Overall, the effects on air quality of very large scale planting of almost all tree species in cities would be positive.

How big?

Trees remove airborne pollutants at three times the rate of grassland. Trees at the edge of woodland are more effective at removing atmospheric pollutants than trees in the centre of woodland. This is due to both larger leaf areas and greater exposure to the wind. By planting trees in all possible sites in the West Midlands (doubling the number of trees), the concentration of small particles could be reduced by 25%. This could lead to a reduction of 140 deaths caused by airborne particles each year in the West Midlands.

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This guide was compiled by Hope Stewart, Sue Owen, Rossa Donovan, Rob MacKenzie & Nick Hewitt of Lancaster University and Ute Skiba & David Fowler of CEH Edinburgh. The research was funded by the Natural Environment Research Council's Urban Regeneration and the Environment (URGENT) programme (grant GST/02/2236).

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