‘Magnetic trees’ and human health

In recent years, much awareness has been raised about the long-term negative health impacts of air pollution, with significant associations identified between air pollution levels and mortality (Elliot et al., 2008). Whilst these pollution/illness links are strongest for respiratory illness, air pollution is also a possible contributing factor to development of cardiovascular illness, cancer and even Alzheimer’s disease (e.g. Calderon-Garciduenas et al., 2004; Morris et al., 1995). These links with adverse health effects have resulted in the introduction of ‘Air Quality Standards’ in many countries, with legal limits for the most significant and/or harmful pollution components.

Particulate matter below 10 μm in diameter (PM$_{10}$), especially particles below 0.1 μm (PM$_{0.1}$), is considered to be the most harmful air pollution component (Donaldson, 2003). It can be breathed deep into the respiratory system (figure 1), and there is no known minimum level at which adverse health effects do not occur (Bealey et al., 2007).

For example, living in an area with PM$_{10}$ levels as low as 10 μg/m$^3$ (i.e. less than half the current European legal air quality standard) has been associated with an 8 % increase in the risk of lung cancer mortality (Elliot et al., 2007).

**Figure 1:** International organization for standardization (ISO) respirable conventions (ISO IS 7708, 1995)
Anthropogenic (man-made) PM$_{10}$, containing potentially toxic metals such as lead, zinc and iron (Al-Alawi et al., 2007), is produced in large quantities by fuel combustion in vehicle engines (Maricq et al., 1999) and in industrial processes. In Europe, with the introduction of legally binding emission reduction commitments, industrially-sourced PM$_{10}$ is declining. However, vehicle use, especially short-journey vehicle use (< 8 km), is increasing internationally (DfT 2007), thereby increasing human exposure to PM$_{10}$.

High spatial resolution measurement of air pollution is thus becoming increasingly important - but is currently not always achieved. For example, if you live outside a big city like London, the likelihood is that the air quality of your whole town is measured by just one or two fixed monitoring stations. Additionally, to reduce the risk of vandalism, the inlets for many of these monitoring stations are situated at heights in excess of 3 metres. Recent research shows that traffic-derived PM$_{10}$ is greatest at approximately 0.3 metres (toddler head height), with values 50% lower at 1.5 metres (adult head height). Thus, conventional fixed monitoring stations sampling at 3 metres are unlikely to provide representative data for human exposure (e.g. Maher et al., 2008; Matzka and Maher, 1999; Mitchell and Maher, subm). This problem of sparse and possibly unrepresentative pollution measurement might be overcome by making use of ‘magnetic’ roadside trees.

Magnetic biomonitoring involves application of laboratory-generated magnetic fields to pollutant particles (PM$_{10}$) collected passively by plants, including, critically, by roadside tree leaves (figure 2). Close to the roadside, the magnetic properties of tree leaves change markedly, because the leaves act as pollution collectors and many of the pollutant particles they catch are strongly magnetic. When different
magnetic fields are applied to leaf samples and their resultant magnetic remanences measured, information can rapidly be gained regarding the concentration, particle size and mineralogy of the leaf-collected pollution particles.

Figure 2: Sampling/measurement procedure for magnetic biomonitoring; Leaves ‘catch’ pollutant particles (as shown in the scanning electron microscopy (SEM) image). The roadside leaves are sampled and taken to the laboratory. Magnetic fields are applied and remanence values measured, giving detailed information regarding the leaf-surface pollutant particles.

The leaf magnetic remanence values have been found to be strongly correlated with ambient particle concentrations, a finding independently tested by measurement of co-located pumped air samplers (figure 3). Thus, roadside leaf magnetic values can be used to calculate ambient PM$_{10}$ levels at any tree location throughout the urban environment (Mitchell and Maher, subm). This fast new analytical

Figure 3: Correlation between leaf magnetic and co-located ambient PM$_{10}$ values ($R^2 = 0.72$, $\sigma = 0.01$, $n = 22$)
capability is critical in the context of health implications, given the serious adverse health effects associated with PM$_{10}$ as outlined above and the current spatial scarcity of PM$_{10}$ data.

Figure 4: SEM image of particulate matter deposited on a leaf sampled from a roadside tree in a highly-trafficked area of Lancaster, UK. Some examples of ‘spherules’ are highlighted by
Magnetic remanence measurements on roadside lime tree (*T. platyphyllos*) leaves located around Lancaster, UK, for example, corroborate the observed strong trend of increasing leaf magnetic remanence and PM$_{10}$ values with increasing proximity to heavily-trafficked roads. Analysis of mineralogy-specific magnetic parameters identifies that the dominant magnetic mineral present in the ambient particulate pollution is magnetite. Comparing the leaf magnetic properties with those of magnetites of known grain size, the dominant size of the leaf magnetite particles is between ~0.1 - 1 μm (Maher, 1988). This is in agreement with the particle sizes observed upon visual examination of the leaf and air filter samples with a scanning electron microscope (SEM), as in figure 4. This size fraction lies within the ‘high-risk respirable’ convention (figure 1); i.e. particles that can penetrate to the unciliated regions of the lung with potential significance in development of deep lung diseases such as pneumoconiosis (Colls, 2002).

The fine (<1 μm) pollution particles mainly comprise iron-rich ‘spherules’ (previously melted droplets) associated with fuel combustion. The larger particles are more angular and rich in aluminium and silica, consistent with particles from natural sources (e.g. from soil).

Lead, a significant neurotoxin even at low levels of exposure (Needleman and Landrigan, 2004), is strongly associated with the sub-micrometre, traffic-derived PM$_{10}$ (Maher et al., 2008). Potential adverse health effects of lead exposure include liver and kidney damage, hearing impairment and retardation of cognitive development in children (e.g. Koller et al., 2004, Lanphear et al., 2000). Thus, biomagnetic monitoring can have a critical role in identifying and mapping areas with elevated traffic-derived PM$_{10}$ levels, crucial for targeting mitigation measures for exposure reduction. Further, magnetic biomonitoring can be used to combine not just monitoring of pollution but actual
reduction of pollution exposure; trees can ‘filter’ out PM$_{10}$ by up to $\sim 20\%$ (e.g. Bealey et al., 2007; Mitchell and Maher, subm). Targeted planting, and maintenance of low level foliage, at locations with high PM$_{10}$ levels can therefore provide significant protection against exposure to PM$_{10}$ at those areas shown by magnetic biomonitoring to be the worst affected.

In addition to addressing traffic-derived pollution, magnetic biomonitoring can also be used for high-resolution monitoring of point source pollution, e.g. from an industry chimney stack. As previously mentioned, traffic-sourced PM$_{10}$ peaks at approximately 0.3 metres, and decreases with increased height from the ground. Thus, point source pollution (which tends to be more pervasive over a larger area) may be distinguished from more localised traffic-derived pollution by sampling leaves from above 1.5 metres height, and at distances exceeding tens of metres from the road.

Cheap and rapid high-resolution leaf magnetic sampling can be undertaken over a large area around the point source, and the results interpolated (values calculated using multiple nearby data points) to enable a PM$_{10}$ value to be estimated for any location within the study area (figure 5). These data can then be used to assist in identifying point pollution sources and the spatial distribution and loadings of their pollution ‘plumes’. Such information is required so that pollution reduction strategies and costs can be implemented and attributed. The biomagnetic data can also be used to assess the accuracy of the current generation of pollution plume models.
Different tree species have different efficiencies for collection of PM$_{10}$; leaves with ridges or hairy surfaces have a greater ability to remove PM$_{10}$ from the air than those with shiny or waxy surfaces. Thus inter-species ‘calibration’ of magnetic and PM$_{10}$ levels has also been established (Mitchell and Maher, *in prep*) enabling maximum spatial coverage.

In conclusion, biomagnetic monitoring is a cheap, fast and robust method for collection of particulate pollution data at unprecedentedly high spatial resolution. Leaf magnetic remanence values can be used to: estimate PM$_{10}$ levels; assess the dominant particle size fractions; identify key ‘target’ areas for pollution reduction; and monitor the ‘filtering’ effect of roadside vegetation screening. Thus, ‘magnetic trees’ can be a key tool for decreasing urban pollution and enhancing human health.
References: