Forest Research

Health Benefits of Street Trees

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Summary

A literature review was commissioned to assess economic evidence on the health benefits provided by street trees[1]. This will feed into research on climate change adaptation planned by Forest Research and help inform the countries on existing evidence relevant to health objectives in their respective forest strategies and other research.

Focusing upon the role of street trees in moderating the climate and environment of urban areas, the following benefits were considered:

- reducing air pollution,
- providing an environment conducive to physical activities,
- reducing stress and improving mental health,
- reducing noise levels,
- cooling air in summer by giving shade (including associated savings to the National Health Service (NHS) from avoided heat stroke),
- reducing ultraviolet radiation through shading (including associated savings to the NHS from avoided skin cancer),
- reducing wind speeds in winter thereby reducing heat loss from buildings.

The review showed that there is a growing body of research generally, but not unanimously, confirming the above benefits of street trees. However, few economic estimates of associated health impacts have so far been published for the effects specifically of street trees. Research on benefits such as reduction in noise, ultraviolet radiation and wind speeds in winter, is mainly limited at present to initial physical measurements.

Keywords: health benefits, street trees, urban forests, urban parks, greenspace.

[1] The term 'street trees' is often used in the literature to mean all trees within urban areas and not just those lining streets. This study focuses on trees in urban areas because this is where the majority of population lives, and is probably where most health benefits are experienced. Health benefits of trees in more remote areas are not covered explicitly by this study.

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1 Introduction

Health issues, including how to improve and promote the health of the UK population and reduce the cost of ill-health to the NHS are always near the top of the public finance agenda. Quality of life, well-being and health objectives have been part of each country's forest strategy (ETWF, 2008; FCS, 2009; FCW, 2009).

The review does not focus on any particular country but draws on a wide pool of research publications in English considered relevant to the whole of UK. It aims to be of interest both to other researchers and to government policy advisors.

The literature review of health benefits of street trees builds upon a review of street trees valuation systems (Sarajevs, 2010), and the Forestry for People study (Edwards *et al.*, 2008) which quantified impacts of Scottish forests on physical health (by promoting physical activity and reducing air pollution) and on mental well-being.

Many publications state that street trees and urban forestry can play a large role in climate change adaptation strategies by helping to mitigate extreme weather events such as floods and heat waves which may occur more often as temperatures increase. For example, (Konijnendijk and Randrup, 2004) argue that by providing settings for physical exercise, reducing ultraviolet radiation and air pollution, and reducing stress urban greenspace can benefit physical and mental health. Moreover, urban forests moderate urban climates, for instance by cooling the air, reducing wind speeds and by giving shade (as well as protecting soils, reducing stormwater runoff and supporting biodiversity).

2 Aims of the review

This study aimed to assess recent evidence of health benefits provided by street trees focusing upon their role in moderating urban climates and environments. Special attention was given to economic estimates of such benefits. Benefit estimates for woodlands were presented whenever evidence on health benefits provided by street trees were lacking.

3 Methodology

A literature review was conducted using two major online databases for academic research: ISI (Information Sciences Institute) Web of Knowledge and Google Scholar[2].

The review focused on the most recent published evidence, i.e. years 2000-2009.

Street trees in rural locations may provide similar health benefits to those in urban ones.[3] However, no published research on health benefits of street trees in rural areas was yielded by the above literature searches.

4 Results

Subsections below contain reviews of relevant literature on benefits of street trees.

4.1 Cooling and shading in summer

The benefits of cooling and shading provided by trees could reduce the incidence (especially in summer) of heat stroke and other heat-related health problems.

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[2] The following search string was used: "health (street OR urban) (trees OR forest*)". This yielded 530 hits from the Web of Knowledge database (all records were viewed) and over 34 thousands results from the Google Scholar search engine (of which the first 750 records were viewed). As it did not yield any results on noise or ultraviolet radiation reduction benefits of street trees, a separate search on ISI Web of Knowledge was conducted with the following search string: "(sound OR noise) tree*" refined by: Subject Areas= (Forestry OR Environmental Sciences & Ecology) AND General Categories= (Social Sciences). This yielded 513 hits of which only four were considered relevant. Ad hoc searches using Google and Forest Research and Forestry Commission colleagues helped uncover some useful additional references.

[3] To the extent that rural trees affect fewer people and create more modest changes in pollution levels and other environmental conditions, associated health benefits may be less important than those of urban trees.

Many publications mention the cooling effect of greenspace and vegetation. However, only a few deal with the issue in detail. Four such papers were identified (Baris *et al.*; Champiat; Lafortezza *et al.*; Rosenzweig *et al.*), all published in 2009. None of the papers deal exclusively with street trees but all mention street trees as an important and effective urban heat island mitigation strategy. The majority of papers deal with technical issues of temperature and humidity measurement and forecasting in an urban heat island[4] environment (Baris *et al.*, 2009; Champiat, 2009; Rosenzweig *et al.*, 2009).

For example, comparisons of below-canopy and open-site air temperatures at 14 forest sites in Switzerland in summer showed significant differences with temperatures up to 5.2°C lower under a canopy (Renaud and Rebetez, 2009). Similarly temperature measurements in greenspaces and nearby residential locations in the city of Ankara, Turkey, showed greenspaces being cooler with temperature differences of up to 5.2°C (Baris *et al.*, 2009). Focusing on cooling through evapotranspiration, modelling studies in Greater Manchester, UK, showed differences in maximum surface temperature for the 98th percentile summer day of around 12°C between built environments (e.g. town centres) and greenspace areas (woodlands) (Gill *et al.*, 2007, p. 122). Research showed that vegetation is more effective in cooling than increases in albedo[5] of built environment (Rosenzweig *et al.*, 2009).

None of the studies examines economic benefits that can be attributed to street trees due to their role in cooling and the corresponding reduction in excess mortality[6]. The excess mortality due to heat waves can be quite large. For example, over 2,000 excess deaths are estimated for England and Wales for the heat wave in 2003 (Johnson *et al.*, 2005). The only UK case study identified was undertaken in Gateshead (north-east England) and is a study of urban residents perception of benefits of green areas (urban parks) during heat waves (Lafortezza *et al.*, 2009). Based on survey responses (n = 400), the study showed that longer and more frequent visits to greenspaces generate

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[4] An urban heat island (UHI) is a metropolitan area which is significantly warmer than its surrounding rural areas (http://en.wikipedia.org/wiki/Urban_heat_island).
The annual mean air temperature of a city with 1 million people or more can be 1–3°C warmer than its surroundings. In the evening, the difference can be as high as 12°C. (US Environmental Protection Agency: http://www.epa.gov/hiri/).

[5] The albedo of an object is the extent to which it diffusely reflects light from light sources such as the Sun. It is therefore a more specific form of the term reflectivity. (http://en.wikipedia.org/wiki/Albedo)

[6] "excess mortality" is defined as 'a premature death, or one that occurs before the average life expectancy for a person of a particular demographic category.' http://medical-dictionary.thefreedictionary.com/excess+mortality (based on Mosby's Medical Dictionary, 8th edition, 2009, Elsevier).

significant improvements in the perceived benefits and well-being of users and alleviate discomfort of extreme heat[7].

There is, however, an older strand of literature from 1990s originating from the United States that examines the economics of cooling effect of street trees on energy consumption for air-conditioning in buildings (Akbari and Konopacki, 2004; Akbari *et al.*, 2001; McPherson and Simpson, 2003) rather than the impact of street trees on health during extreme weather events. For example, in California peak load reduction by existing trees is estimated to result in a 10% saving in utility bills valued at approximately $ 778.5 million annually, or $ 4.39/tree (McPherson and Simpson, 2003).

In summary, while cooling effects of street trees are widely recognised and experimentally measured, the economic benefits from the corresponding reduction in excess morbidity or mortality are not presented in the literature.

4.2 Reduce ultraviolet radiation through shading

Shading from harmful ultraviolet (UV) radiation[8] is another benefit attributed to street trees. This could be expected to reduce eye cataracts and morbidity and mortality from skin cancer. Few references were found (Grant and Heisler, 2006; Grant *et al.*, 2002; Heisler and Grant, 2000; Heisler *et al.*, 2003; NUFU, 1999), and no economic estimates.

Trees greatly reduce UV irradiance in their shade when they obscure both the sun and sky. Forested areas with closed tree canopies provide nearly total protection. However, where much of the sky is left in view, UV radiation is much more prevalent (reduction in UV can be as little as 39%) than suggested by the appearance of visible shadow (Grant *et al.*, 2002; Heisler and Grant, 2000; Heisler *et al.*, 2003). Therefore, where many large street-tree crowns block much of the sky, high level protection from UV is achieved for pedestrians, even in spots with direct sun through gaps between crowns. However, large trees tend to have high maintenance costs which may offset these benefits (Heisler and Grant, 2000).

For latitudes between 15 and 60 degrees, ultraviolet protection factors (UPF) were less than 2 for less than 50% tree cover. A UPF of 10 was possible at all latitudes for tree canopy cover of 90% (Grant *et al.*, 2002).

[7] Based on bivariate correlations between variables measuring the use of greenspaces and the outcomes reported by respondents and multiple regression analysis.

[8] Especially the part of sun light spectrum called the UV-B radiation with 280-320 nm wavelengths.

Other estimates show that an individual tree can reduce exposure to ultraviolet radiation to one sixth to one-tenth of full sun, i.e. a Sun Protection Factor (SPF) of 6 to 10 (NUFU, 1999).

4.3 Reduce wind speeds in winter

Reduced wind speeds could reduce morbidity and mortality from accidents involving pedestrians and cyclists being pushed over, or blown into the line of other traffic by strong winds, as well as hypothermia-related health problems.

No associated health benefits estimates are reported in the literature with respect to street trees. Only some building energy savings estimates are available (Heisler, 1986; 1989; Peper *et al.*, 2007). These suggest potential annual building energy savings[9] could be as high as 25% (Heisler, 1986).

An interesting study (Liu and Harris, 2008) shows the potential for energy saving through trees sheltering buildings from wind. The research showed that optimally placed[10] shelterbelt trees can reduce energy consumption (heating costs) in offices[11] in Scotland, by up to 18%. There is no economic cost-benefit analysis in the study.

4.4 Reduce air pollution

There is a lot of evidence of trees reducing air pollution and of the economic benefits of this (Jim and Chen, 2008; Nowak *et al.*, 2006; Nowak *et al.*, 2002; Nowak *et al.*, 2007; Peper *et al.*, 2007; Tiwary *et al.*, 2009). Economic benefits are usually estimated in terms of investment cost necessary if the air was instead purified by technological means[12]. Street trees improve air quality in five main ways (Peper *et al.*, 2007):

- Absorbing gaseous pollutants (ozone [O_3], nitrogen dioxide [NO_2]) through leaf surfaces
- Intercepting particulate matter (e.g., dust, ash, dirt, pollen, smoke)
- Reducing emissions from power generation by reducing energy consumption
- Releasing oxygen through photosynthesis

[9] The bulk of energy savings would occur during winter. However, in places with hot summers tree shading may result in significant savings on air conditioning as well.

[10] With respect to the prevailing winds and possible solar gains into the sheltered building during wintertime. A single row of trees is suggested with shrubs planted at the base (Liu and Harris, 2008, p. 119).

[11] A typical two-storey, middle-sized open-plan office building was modelled.

[12] The same approach (technological costs rather than health benefits) seems to be adopted by a widely used i-Tree street tree valuation system, main website: http://www.itreetools.org/ .

- Transpiring water and shading surfaces, resulting in lower local air temperatures, thereby reducing O_3 levels

Links from reduction of air pollution due to street trees and respiratory diseases and related deaths are less well established. Two recent papers, one from the US and one from the UK, report on such links (Lovasi *et al.*, 2008; Tiwary *et al.*, 2009). An increase in density of street trees was associated with lower prevalence of asthma, but not with lower hospitalisation for asthma (Lovasi *et al.*, 2008). Controlling for other factors (socio-demographic characteristics, population density and proximity to pollution sources), an increase in tree density of one standard deviation led to a 29% lower early childhood prevalence of asthma.

The UK study (Tiwary *et al.*, 2009) focuses on the role of vegetation in mitigating the effects of particulate (PM_{10}) pollution. Predicting (using model simulations) the PM_{10} concentrations both before and after greenspace establishment, using a 10 x 10 km area of East London Green Grid as a case study, the paper estimates that 2 deaths and 2 hospital admissions would be averted per year.

A number of guides for evaluating damage costs for key air pollutants and costs of improving air quality are provided by the Department for Environment, Food and Rural Affairs (DEFRA) (DEFRA, 2007; 2008). These guides contain monetised estimates for health benefits due to reduction in air pollution. However, the estimates are not linked specifically to the benefits of trees.

No economic estimates of health benefits provided by street trees through reduction in air pollution were found in the literature. However, an earlier study (Willis *et al.*, 2003, pp.: 4, 24-25) produced lower bound estimates of the net benefit due to pollution absorption by for all woodlands in Great Britain of up to £11 million capitalised in 2002 prices (equivalent to £0.39 million annually). Similarly, for the Scottish woodlands the health benefits of reduction in air pollution were estimated in the range from £4,000 to £260,000 per annum in 2007/08 prices (Edwards *et al.*, 2008, p. 83).

4.5 Environment conducive to physical activities

The presence and access to open greenspace can help promote more active lifestyles. This can have a positive health benefit that is noted and explored in the literature (Atif *et al.*, 2002; Bedimo-Rung *et al.*, 2005; CJC, 2005; Ellaway *et al.*, 2005; Forsyth *et al.*, 2008; Heath *et al.*, 2006; Larsen *et al.*, 2009; Lee, 2007; Lee and Moudon, 2008; Lovell and Roe, 2009).

While many of these papers use a generic ‘greenspace’ terminology in their titles, whenever there are results of surveys the respondents always put the presence of trees

at the top of their priorities for such areas (Atif *et al.*, 2002; Lee and Moudon, 2008). In regression analyses the presence of street trees is found to be a significant positive factor in the level of physical activities undertaken such as walking and cycling (Forsyth *et al.*, 2008; Larsen *et al.*, 2009; Lee, 2007). For example, in one of the studies bicycle traffic increased by more than 20% due to better street-scale design that included planted trees (Heath *et al.*, 2006, S75). Results from a European survey showed that people living in a green environment have a three times higher probability of being physically active, and a 40% smaller probability of being overweight or obese (Ellaway *et al.*, 2005).

However, it is important to emphasise that the argument about the link between health and greenspace is not entirely settled. For example, in a recent large Dutch study no relationship was found between the amount of greenspace in the living environment and whether or not people meet the Dutch public health recommendations for physical activity (Maas *et al.*, 2008).

No economic estimates of health benefits provided by street trees through creating environment conducive to physical activities were found. One study (CJC, 2005) focuses on greenspace in general and woodlands, and is a secondary study (critical review). This found for greenspace in general that a permanent reduction of 1% unit in the UK sedentary population (from 23% to 22%) is estimated to deliver a social benefit of up to £1.44bn per year (£479m if older people are excluded from the calculation). Additionally, for Scotland forest-based health activities were estimated to yield an annual value (due to avoided mortality and morbidity) of between £2.7 million and £99 million (Edwards *et al.*, 2008, p. 82).

4.6 Reduce stress and improve mental health

A positive effect of greenspaces on psychological well-being, including stress reduction and mental health improvements, is reported in a number of studies (Grahn and Stigsdotter, 2003; Groenewegen *et al.*, 2006; Guite *et al.*, 2006; Hansmann *et al.*, 2007; Jackson, 2003; Kaplan, 2001; Nielsen and Hansen, 2007; Pretty *et al.*, 2007; Velarde *et al.*, 2007), including a pioneering paper from the 1980s (Ulrich, 1984). However, none of the papers report any economic estimates of this benefit with respect to street trees. Nevertheless, for Scotland, based upon assuming an improvement in mental health associated with living within a 1km to 3km radius of greenspace (de Vries *et al.*, 2003), the mental health value of greenspace (woodlands) has been estimated at between £7.7m and £12.4m per year (at 2007/08 prices) (Edwards *et al.*, 2008, p. 84).

Only one study (Guite *et al.*, 2006) report findings of research on the link between the physical and urban environment and mental well-being in the UK, focusing on four areas of Greenwich, London. Based upon use of a questionnaire, the results showed that

access to greenspace and neighbour noise were among major factors determining the state of mental well-being.

Another paper used a field survey to assess the restorative effects of visiting an urban forest and a city park in Zurich, Switzerland (Hansmann *et al.*, 2007), where respondents rated their headaches, level of stress, and how balanced they felt both prior to visiting the outdoor location and at the time of being interviewed. The recovery ratio (in terms of the possible improvements on five-point rating scale) for stress was 87%, and the reduction in headaches was 52%. Moreover, positive effects increased with length of visit and the physical level of activities respondents engaged in.

Statistical results from a Danish survey (n = 1196 respondents and logistic regression model) showed that access to a garden or short distances to green areas from dwelling are associated with less stress and lower likelihood of obesity (Nielsen and Hansen, 2007). Based on this evidence, it has been argued that at the building parcel scale "greenery and access to it visually and physically are the principal keys to health" (Jackson, 2003, p.191).

Finally, positive health effects of viewing natural landscapes on stress levels and speed of recovery from stress or mental fatigue, faster physical recovery from illness and long-term overall improvement on people's health and well-being are reported (Lee *et al.*, 2009; Velarde *et al.*, 2007).

4.7 Reduce noise levels

Noise, defined as any unwanted sound, can have a wide range of adverse impacts on human health, public amenity, local ecology, and productivity. Indicative estimates suggest that noise pollution imposed a social cost on England in 2008 in excess of £9 billion per annum. This estimate comprises £5-9 billion in annoyance costs, health costs of around £2 billion, and productivity losses costing another £2 billion (IGCB(N), 2010, p. 6).

Street trees can shelter residents, pedestrians and off-road cycle paths from noise. This is known to reduce stress and improve mental health. However, research publications are very sparse and mainly concentrate on measuring the magnitude of noise reduction (Kim and Oh, 1994; Kotzen, 2004; Leonard and Parr, 1970; Papafotiou *et al.*, 2004; Yamada, 2006) or forest design issues (Yamada, 2006).

Another study argues that only dense, tall and wide plantings reduce noise effectively. This limits the use of plants for noise control to large areas along motorways or near industrial plants. However, plant barriers also reduces the perception of noise and are beneficial psychologically (Clark and Matheny, 2009).

No economic estimates of health benefits from this ecosystem service provided by street trees were found in the literature.

5 Conclusions and recommendations

The review showed that there is a growing body of research generally, but not unanimously, confirming the above health benefits of greenspace and street trees in particular. However, economic estimates of these health benefits are scarcely available at present, especially ones that focus on street trees.

At present a small number of papers move a step forward from asserting and/or researching the link between street trees and health and well-being to estimating a number of avoided excess deaths or hospital admissions. However, none of the reviewed papers took the further step and put a monetary value on the health benefits of street trees.

Research on benefits such as reduction in noise, ultraviolet radiation and wind speeds in winter is especially limited at present.

Potential future research priorities are three-fold and could be facilitated by interdisciplinary cooperation. First, where research on health benefits of street trees is in its infancy and only physical measurements have been made, for example reduction in noise or UV radiation levels due to street trees, health scientists should do standard empirical studies to reveal any measurable health outcomes such as avoided excess morbidity and mortality, increases in quality adjusted life years, avoided hospital admissions and/or treatments. Second, using the above data economists can calculate economic benefits of improved health due to street trees. This can draw upon existing approaches to valuing reduced morbidity and mortality. Finally, economists can apply cost-benefit analysis to various options of urban forest management to recommend the most cost effective options.

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