Environmental Pollution 183 (2013) 104–112

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Does urban vegetation mitigate air pollution in northern conditions?

Heikki Setälä [a,*], Viljami Viippola [a], Anna-Lea Rantalainen [a], Arto Pennanen [b], Vesa Yli-Pelkonen [c]

[a] University of Helsinki, Department of Environmental Sciences, Niemenkatu 73, FIN-15140 Lahti, Finland
[b] National Institute for Health and Welfare, Department of Environmental Health, P.O. Box 95, 70701 Kuopio, Finland
[c] University of Helsinki, Department of Environmental Sciences, P.O. Box 65, FI-00014 University of Helsinki, Finland

ARTICLE INFO

Article history:
Received 15 August 2012
Received in revised form
16 November 2012
Accepted 18 November 2012

Keywords:
Air pollution
Ecosystem services
Passive samplers
Traffic
Urban vegetation

ABSTRACT

It is generally accepted that urban vegetation improves air quality and thereby enhances the well-being of citizens. However, empirical evidence on the potential of urban trees to mitigate air pollution is meager, particularly in northern climates with a short growing season. We studied the ability of urban park/forest vegetation to remove air pollutants (NO_2, anthropogenic VOCs and particle deposition) using passive samplers in two Finnish cities. Concentrations of each pollutant in August (summer; leaf-period) and March (winter, leaf-free period) were slightly but often insignificantly lower under tree canopies than in adjacent open areas, suggesting that the role of foliage in removing air pollutants is insignificant. Furthermore, vegetation-related environmental variables (canopy closure, number and size of trees, density of understorey vegetation) did not explain the variation in pollution concentrations. Our results suggest that the ability of urban vegetation to remove air pollutants is minor in northern climates.

1. Introduction

Due to environmental problems associated with urbanization, the influence of vegetation in mitigating these negative effects has received considerable interest amongst scientists and urban planners (Alberti, 2008; Grimm et al., 2008). For example, urban vegetation is believed to provide various social and health benefits to society, collectively called cultural ecosystem services (MEA, 2005), thus improving the sustainability of cities (Hartig et al., 2003; Leung et al., 2011). The removal of atmospheric pollutants by urban trees and other vegetation, a regulating ecosystem service, has been of particular interest during the past decades. For instance, tree and herb leaves remove particulates by dry deposition (Beckett et al., 2000a; Fowler, 2002; McDonald et al., 2007; McPherson, 1998; Nowak et al., 2006), gaseous pollutants such as NO_2 (Joss and Graber, 1996; Nowak et al., 2006; Takahashi et al., 2005; Yin et al., 2011) and SO_2 (Nowak, 2006; Yin et al., 2011), O_3 (Harris and Manning, 2010; Manes et al., 2012; Nowak, 2006), and organic pollutants (Doty et al., 2007; Keymeulen et al., 1995). However, urban vegetation also affect air quality negatively, including allergenic effects of pollen and fungal spores (Denning et al., 2006; Simon-Nobbe et al., 2008; Taketomi et al., 2006) and by emitting volatile organic compounds (biogenic VOCs), which can eventually form ozone (Abelsohn et al., 2002).

The majority of studies suggesting that urban vegetation is an efficient remover of airborne pollutants are based on large-scale modeling (e.g. Jim and Chen, 2008; McPherson and Simpson, 2003; Nowak et al., 2000) in which the removal of the pollutant is simply a function of deposition velocity, pollution concentration, and some parameters describing forest structure (such as biomass and leaf area index) (Lovett, 1994; Smith, 1990). These models often use data taken from a limited number of sites within a city, which make them unlikely to represent variation in canopy structure and microclimates within a city. Furthermore, such models are based on data from plant chamber studies performed in the field or in greenhouses, where factors influencing plant physiology and their physical–chemical processes have been studied, as well as on studies measuring fluxes of air pollutants often above the tree canopy (e.g. Duyzer et al., 1995; Hargreaves et al., 1992). Only a few studies exist in which pollutant fluxes have been quantified within a forest or at the tree canopy where the uptake of pollutants happens (see Freer-Smith et al., 2005; Joss and Graber, 1996; Harris and Manning, 2010; Streiling and Matzarakis, 2003; Yin et al., 2011). Importantly, accurate measurements on the actual uptake of pollutants, deposition, and re-suspension rates by urban vegetation are not available (Whitlow, 2009). The lack of experimental data, and the various shortcomings related to the ability of current models to quantify pollution removal by urban trees has recently

* Corresponding author.
E-mail addresses: heikki.setala@helsinki.fi (H. Setälä), viljami.viippola@helsinki.fi (V. Viippola), anna-lea.rantalainen@helsinki.fi (A.-L. Rantalainen), arto.pennanen@thl.fi (A. Pennanen), vesa.yli-pelkonen@helsinki.fi (V. Yli-Pelkonen).

0269-7491/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.envpol.2012.11.010

been recognized. For example, Pataki et al. (2011) state that "the removal of atmospheric pollutants by vegetation is one of the most commonly cited ecosystem services, yet it is one of the least supported empirically". In this paper we aim at providing hitherto lacking experimental evidence on the ability of urban vegetation to remove three types of anthropogenic air pollutants under northern conditions in Finland. As urban transport and the concomitant increase in traffic-derived pollutants is an increasing problem in cities throughout the world (Ning and Sioutas, 2010; Walsh and Shah, 1997), special emphasis in the current study is put on the ability of urban parks and forests to remove traffic-derived pollutants. We hypothesize that 1) air quality in tree-covered urban areas is improved compared to open, treeless areas, 2) the removal of air pollutants relates to the volume and structure of the vegetation, and 3) the ability of vegetation to remove air pollutants is elevated in summer (leaf-period) compared to winter.

2. Materials and methods

2.1. Sampling methods

We measured air pollutant levels using dry deposition passive samplers, placed under tree canopies in tree-covered park areas and in adjacent treeless open areas in the cities of Helsinki (60°10′15″N, 24°56′15″E) and Lahti (60°59′00″N, 25°39′20″E) in southern Finland. The pollutants measured were nitrogen dioxide (NO_2), a selection of typical anthropogenic volatile organic compounds (VOCs), and particle deposition. We used diffusive samplers developed by the Swedish Environmental Research Institute IVL for NO_2 (Ferm and Svanberg, 1998), diffusive Carbopack B adsorbent tubes for VOCs (according to the EN ISO 16017-2-standard) and passive collectors developed by IVL for particle deposition (Ferm et al., 2006). NO_2 and particle deposition samplers and their analyses were provided by IVL, while VOC samplers and their analyses by Ramboll Analytics, Lahti, Finland.

NO_2 and VOC samplers are based on molecular diffusion. Despite some limitations in the use of passive samplers, they have been successfully applied in several studies, showing strong agreement with continuous air monitoring (see Krupa and Legge, 2000 for a discussion of passive samplers). The particle sampling method, designed for corrosion studies and based on impaction as well as diffusion of particles on a vertically mounted cylindrical Teflon surface, does not provide straightforward information on the fractions of different particle sizes, such as PM_{10} or $PM_{2.5}$, but provides the mass of deposited particles on a given surface area (here called "particle concentration"). According to Ferm et al. (2006), particle deposition correlated surprisingly well with PM_{10} concentrations when samplers were not situated very close to traffic.

2.2. Sampling sites and dates

Twenty sites, 10 in each city (Fig. 1), were established at the borders of roads with moderate to heavy traffic flows (see below). Each site consisted of a pair of sampling units: one unit in an open area and another under a tree canopy, totaling 40 sampling units. Sampling units within each pair were either on the same or different side of the road. The open areas were typically small- to medium-sized city squares or other treeless areas close to a road. Soil surfaces at these open areas were either completely impervious (often asphalt) or pervious with mown lawns. The tree-covered areas were either urban parks with scattered deciduous trees and lawn as understorey vegetation, or urban forest remnants of mixed forest type and rich understorey vegetation. Exact site dimensions are difficult to quantify due to their convoluted shapes. Mean forest/park size was ca. 3 ha in Lahti and 5 ha in Helsinki, while that of the open site was 0.5 ha in Lahti and ca. 1 ha in Helsinki. Samplers were mounted under a rain shield fixed to an aluminium sampler holder, which was attached to a tree trunk or lamp post by a 40 cm long aluminium rod. The shields and sampler holders were provided by IVL. Sampling units were mounted 2.5–3.5 m above ground: on lamp posts in open areas and on tree trunks directly under the canopy in tree-covered areas. Within each site, sampling units were placed at equal distances from the road where possible. However, due to the lack of suitable mounting structures, sampling units in open areas were situated, on average, 4 m closer to the road compared to those in tree-covered areas. Consequently, for 13 of the 20 pairs the open area sampling units were closer to the road. Distances from the road to the sampling units varied between 8 and 65 m for open areas and between 22 and 56 m for tree-covered areas. The difference in distance within individual sampling pairs varied from 0 to 22 m (0 meaning the pair was situated at equal distance from the road).

Measurements were made during two seasons: from 9 August to 10 September 2011 (late summer, from here on called August) and from 7 March to 11 April 2012 (late winter, from here on called March). During both sampling periods the NO_2 and particle samplers were deployed for 30 days and the VOC samplers for 14 days.

General properties of the study sites were characterized by measuring a set of environmental variables at the sites (Table 1). At the tree-covered areas, canopy closure was estimated from two upward facing photographs taken 1 m above the ground. One photograph was taken at the sampling unit and the other one 5 m toward the road from the sampling unit. The proportion of non-visible sky (a proxy for canopy closure) was calculated using image processing software. The number, size (diameter at breast height including trees with DBH $>$ 0.8 cm) and species composition of trees were measured from a sector covering 90° from the sampling unit toward the road that delineates the area. The number of conifers was measured due to their evergreen nature and higher leaf surface area and associated elevated pollutant removal capacity. Due to variation in distances of the placement of sampling units to the roads and, thus, variation in the sector areas, the number of trees was converted to number of trees per 100 m^2. Understorey vegetation structure (shrubs, bushes) was estimated visually from photographs taken from the sampling unit toward the road, and classified into dense, intermediate and meager. Understorey vegetation varied between the tree-covered areas so that at sites 1, 5, 8, 9, 11, 15, 16, 17, 18 and 20 it was particularly dense, while sites 2, 3, 7, 10 and 19 were virtually devoid of understorey vegetation (meager), and sites 4, 6, 12, 13, and 14 had intermediate understorey vegetation. The degree of canopy closure in the tree-covered sampling units was slightly lower in Lahti (68.2% $\pm$ 21.6; mean $\pm$ SD) than in Helsinki (80.7% $\pm$ 11.9). Similarly, fewer trees were recorded from the Lahti (23.3 $\pm$ 11.5) compared to the Helsinki (32.3 $\pm$ 12.9) sampling units, with large trees (DBH $>$ 32 cm) comprised 39.4% ($\pm$23.2) and 23.9% ($\pm$17.2) of all trees in Lahti and Helsinki, respectively. Sampling units in both cities were dominated by deciduous trees ($>$92% $\pm$ 10). Traffic flows were ca. 1.5 times higher in Helsinki than in Lahti (Table 1). Traffic flows were obtained from data provided by the City of Helsinki (2011) and the City of Lahti (2012). Regarding general pollution levels measured from several sampling locations in Lahti and Helsinki in 2011, mean annual concentrations for NO_2 were 12–30 μg/m^3 in Lahti and 7–50 μg/m^3 in Helsinki, for

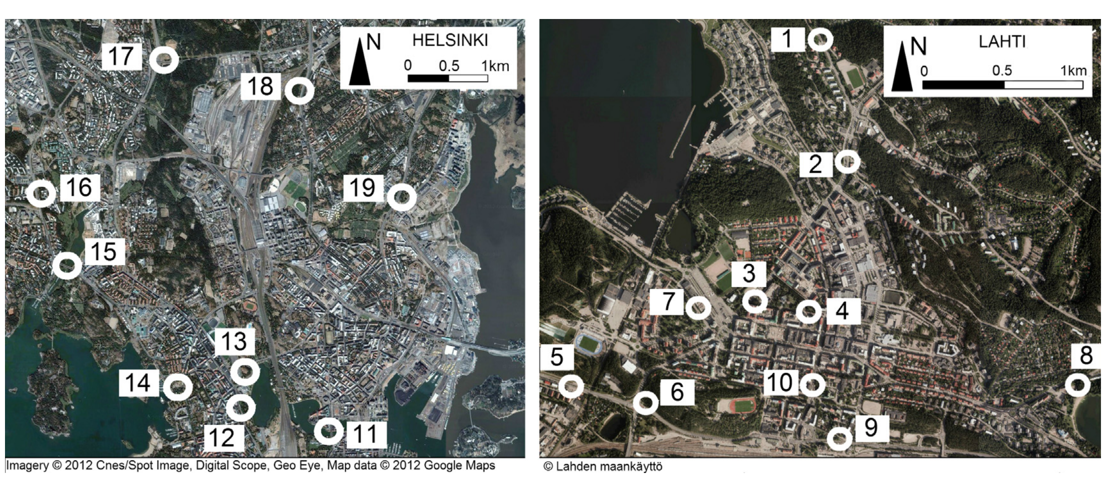

Fig. 1. Location of the study sites in Helsinki (left panel) and Lahti (right panel). Within each site (displayed as a circle) air quality was measured in open and tree-covered area. Site number 20 in Helsinki was situated 8.8 km to the NE from site 19.