Landscape and Urban Planning 158 (2017) 39–47

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Urban forests near roads do not reduce gaseous air pollutant concentrations but have an impact on particles levels

Vesa Yli-Pelkonen[a,*], Heikki Setälä[b], Viljami Viippola[b]

[a] University of Helsinki, Department of Environmental Sciences, P.O. Box 65, FI-00014, Finland
[b] University of Helsinki, Department of Environmental Sciences, Niemenkatu 73, FI-15140 Lahti, Finland

HIGHLIGHTS

- Gaseous pollutant concentrations did not differ between tree-covered and open areas.
- Particle pollutant levels were significantly lower in tree-covered areas.
- Vegetation-related variables did not explain the difference in particulate levels.

ARTICLE INFO

Article history:
Received 3 October 2015
Received in revised form
14 September 2016
Accepted 24 September 2016

Keywords:
Air pollution
Ecosystem services
Near-road environment
Passive sampling
Urban trees
Urban vegetation

ABSTRACT

The ability of urban vegetation to improve air quality for the benefit of urban residents is often considered fact since plants can absorb and capture air pollutants. However, there is little empirical evidence that urban air quality at the local scale is improved by the presence of, e.g. trees, especially in northern climatic regions. We studied the impact of urban forest vegetation on the levels of five types of air pollutants (NO_2, ground-level O_3, anthropogenic and biogenic VOCs, and particulate matter) in near-road environments during summer (June) using passive samplers in Helsinki, Finland. Concentrations of gaseous pollutants did not differ significantly between tree-covered and adjacent open areas, while particle pollutant levels were significantly lower in tree-covered areas than in adjacent open, treeless areas. Vegetation-related variables (canopy closure, tree number and size, and ground vegetation) did not explain differences in air quality. Our results suggest that the role of urban, mostly deciduous, vegetation is negligible in improving local air quality, in terms of the anthropogenic pollutants measured here, in northern climates. However, air particulate pollution, which is likely to be dominated by large-sized particles in our study, can be reduced by urban vegetation.

1. Introduction

Poor air quality due to air pollutants is amongst the most recognized environmental problems in urbanized areas around the world. In Europe, the levels of air pollutants have generally decreased within the past decades, but in many urban areas the levels of particulate matter, nitrogen dioxide (NO_2), ground-level ozone (O_3), and anthropogenic volatile organic compounds (AVOC) are still high enough to cause severe risk to human health (EEA, 2014). Most of these air pollutants originate from energy production and road traffic (EEA, 2014).

Although reducing air pollutant emissions is likely to be the most effective way to improve air quality (EEA, 2014), it is widely believed that vegetation – due to its ability to absorb and capture air pollutants with its large leaf area – can be used to mitigate urban air pollution problems (Beckett, Freer-Smith, & Taylor, 2000a; Nowak, 2006; Nowak, Crane, & Stevens, 2006). For example, trees and herbaceous plants capture particulate pollution by dry deposition on their large leaf surfaces (Hofman, Stokkaer, Snauwaert, & Samson, 2013; Räsänen et al., 2013; Weber, Kowarik, & Säumel, 2014).

Furthermore, trees and other vegetation can absorb gaseous air pollutants, mainly from air to leaf, where gases such as NO_2 (Chaparro-Suarez, Meixner, & Kesselmeier, 2011; Rondón & Granat, 1994; Takahashi et al., 2005), O_3 (Harris & Manning, 2010; Manes et al., 2012; Wang et al., 2012) and anthropogenic volatile organic compounds (AVOC) (Doty et al., 2007; Keymeulen, Schamp, & Van

* Corresponding author.
E-mail addresses: vesa.yli-pelkonen@helsinki.fi (V. Yli-Pelkonen), heikki.setala@helsinki.fi (H. Setälä), viljami.viippola@helsinki.fi (V. Viippola).

http://dx.doi.org/10.1016/j.landurbplan.2016.09.014
0169-2046/

Langenhove, 1995) are absorbed through the stomata into the leaf interior. Consequently, the mitigation of air pollution is often considered an important ecosystem service provided by urban vegetation (e.g. Chaparro & Terradas, 2009; Jim & Chen, 2008; Manes et al., 2012; Nowak et al., 2008).

orests and other vegetation in rural and urban areas emit biogenic volatile organic compounds (BVOC) while human activities produce AVOCs, which, together with NO_x ($NO + NO_2$), play a key role in the formation of ozone (O_3) in the tropospheric air (Calfapietra et al., 2013; Loreto & Schnitzler, 2010). Under VOC-limited conditions, ground-level O_3 levels are usually lower in urban (high NO_x levels) than in rural areas with NO_x-limited conditions (low NO_x levels, but higher BVOC levels) (Calfapietra et al., 2013; EEA, 2014). However, in recent years, O_3 levels in European and North American cities have increased more than in rural sites, although peak values are decreasing in both environments (Paoletti, De Marco, Beddows, Harrison, & Manning, 2014).

Despite the wealth of studies suggesting that urban vegetation is able to purify air for the benefit of urban inhabitants, contradictory results and comments have emerged recently (Gromke & Ruck, 2009; Harris & Manning, 2010; Pataki et al., 2011, 2013; Vos, Maiheu, Vankerkom, & Janssen, 2013). Critique is based on the interpretation of model studies, according to which ambient air quality should uniformly be improved by the presence of vegetation in the urban environment, where pollutant concentrations are high (e.g. Baumgardner, Varela, Escobedo, Chacalo, & Ochoa, 2012; Hirabayashi, Kroll, & Nowak, 2012; McDonald et al., 2007; Morani, Nowak, Hirabayahsi, & Calfapietra, 2011; Nowak, Hirabayashi, Bodine, & Hoehn, 2013).

Only a few studies exist in which pollutant levels have been measured locally, e.g. within a forest or park canopy and compared to pollution levels in adjacent open areas (see Brantley, Hagler, Deshmukh, & Baldauf, 2014; Cavanagh, Zawar-Reza, & Wilson, 2009; Freer-Smith & Beckett, 2005; Harris & Manning, 2010; Setälä, Viippola, Rantalainen, Pennanen, & Yli-Pelkonen, 2013; Streiling & Matzarakis, 2003; Viippola, Rantalainen, Yli-Pelkonen, Tervo, & Setälä, 2016; Yin et al., 2011). As such, to enhance our understanding on the uptake, deposition, and re-suspension rates of pollutants by urban vegetation, more on-site, small-scale measuring campaigns are needed (Pataki et al., 2011, 2013; Whitlow, 2009).

Our main objective is to explore the ability of urban vegetation to purify gaseous and particulate air pollutants of anthropogenic, mostly traffic-derived origin under northern summertime conditions in the near-road environment in Finland. This study builds on the same empirical principles as applied by Setälä et al. (2013), in which air pollutant levels (concentrations of NO_2 and VOCs and mass deposition of particles) were measured in open and tree-covered areas in late summer and winter using passive samplers in urban near-road environments in two cities (Helsinki and Lahti) in Finland. The present study was conducted during midsummer (mainly June) when the total leaf-area and gas exchange between leaves and the ambient air is expected to be higher than in Setälä et al. (2013). The sampling protocol of the present study was also slightly different by fine tuning the position of the sampling sites in relation to the prevailing wind direction. Based on previous findings in similar environments (Setälä et al., 2013) we hypothesized that concentrations of gaseous air pollutants should not differ between urban tree-covered and open, treeless areas in near-road environments, while air particulate levels (mass of all deposited particles) should be lower in such tree-covered areas. We also assumed that the removal of pollutants, particularly air particulates, should relate to the volume and structure of vegetation in the tree-covered areas.

2. Methods

2.1. Sampling methods

We measured air pollutant levels using dry deposition passive samplers, placed either under tree canopies in tree-covered areas or in adjacent treeless open areas in near-road environments in the Helsinki Metropolitan Area (60°10′15″N, 24°56′15″E), southern Finland (Fig. 1). The air pollutants measured were i) nitrogen dioxide (NO_2), ii) ground-level ozone (O_3), iii) a selection of typical anthropogenic volatile organic compounds (AVOCs), iv) biogenic volatile organic compounds (BVOCs), which is a selection of the most common monoterpenes in Finnish forests alongside isoprenes (Lindfors & Laurila, 2000), and v) particulate matter. For NO_2 and O_3 we used diffusive samplers developed by the Swedish Environmental Research Institute IVL, where the gas is adsorbed to a filter paper inside the collector and the amount of gas is analyzed by extracting it from the filter to distilled water, after which the amount of gas is determined with a spectrophotometer (Ferm & Svanberg, 1998). AVOCs and BVOCs (see Table 3 for the list of compounds) were sampled using diffusive Carbopack B adsorbent tubes and analyzed according to the EN ISO 16017-2 – standard, where the concentrations of the studied compounds, counted from individual adsorbent tubes, are determined by comparing them to compound-specific standard substances. VOC results are presented as total AVOCs (=T-AVOCs, including all the sampled AVOC compounds) and as total BVOCs (=T-BVOCs, including all the sampled BVOC compounds). Particle pollution levels were measured using passive collectors developed by IVL (Ferm, Watt, O'Hanlon, De Santis, & Varotsos, 2006). NO_2 samplers and their analyses were provided by Metropolilab, Helsinki, Finland, O_3 and particle samplers and their analyses by IVL, and VOC samplers and their analyses by Ramboll Analytics, Lahti, Finland.

The sampling of NO_2, O_3 and VOCs is based on molecular diffusion. The method has some limitations, but has been successfully used in numerous studies, with results strongly in line with continuous air monitoring (Ayers et al., 1998; HSY, 2014; Krupa & Legge, 2000). The passive particle sampling method is based on the deposition of particles by impaction and diffusion on a vertically-mounted cylindrical Teflon surrogate surface. The method does not provide information on the specific particle size fractions, but provides the mass of deposited particles on the sampler surface. Mass is calculated by weighing the surrogate surface before and after exposure. The surrogate surfaces are equilibrated for 24 h before weighing in a weighing room at 20 °C and 50% relative humidity (Ferm et al., 2006). Ferm et al. (2006) noted that particle deposition on Teflon correlated well with PM_{10} concentrations when samplers were not situated in the immediate vicinity of roads.

2.2. Sampling sites and dates

Ten sampling sites [different from those in Setälä et al. (2013)] in the Helsinki Metropolitan Area (eight in the city of Helsinki, and one each in the neighboring cities of Espoo and Vantaa, Fig. 1b) were established on the northern side of roads oriented in an east-west direction with moderate to heavy traffic flows (Table 1). This ensured that air pollutant collectors resided downwind from traffic-derived air pollutants. There were no major intersections or roads oriented in a south-north direction, or other roads oriented in a west-east direction to the north of the measuring sites that could potentially have biasing effects. Each of the 10 sites consisted of a pair of sampling units placed on the northern side of the road: one unit in an open area and another in a tree-covered area. The sampling sites were approximately level with the road surface. The open areas were meadows, grasslands or other treeless areas. The soil surface at these open areas was either completely pervious or