Landscape and Urban Planning 128 (2014) 14–22

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Differences in magnitude and spatial distribution of urban forest pollution deposition rates, air pollution emissions, and ambient neighborhood air quality in New York City

Kristen L. King[a,*], Sarah Johnson[b,1], Iyad Kheirbek[b,1], Jacqueline W.T. Lu[c,2], Thomas Matte[b,1]

[a] New York City Department of Parks and Recreation, Central Forestry, Horticulture, & Natural Resources, 1234 Fifth Avenue, New York, NY 10029, USA
[b] New York City Department of Health and Mental Hygiene, Bureau of Environmental Surveillance and Policy, 125 Worth Street, CN34E, Room 326, New York, NY 10013, USA
[c] New York City Department of Parks and Recreation, Central Forestry, Horticulture, & Natural Resources, Olmsted Center, Flushing Meadows Corona Park, Flushing, NY 11368, USA

HIGHLIGHTS

- Variation exists in the pollution removal potential of New York City's urban forest.
- Land Use Regression reveals that tree cover represents absence of emissions sources.
- Total NO_2 and PM_{10} emissions exceed canopy deposition rates at the county level.
- PM_{10} canopy deposition is slightly higher than traffic-based emissions.
- Estimated total emissions of both pollutants are spatially disconnected from deposition.

ARTICLE INFO

Article history:
Received 10 June 2013
Received in revised form 26 March 2014
Accepted 6 April 2014
Available online 22 May 2014

Keywords:
Urban forest
Air quality
Nitrogen dioxide
Particulate matter
New York City
Land Use Regression

ABSTRACT

Urban forest pollution removal potential has not been well explored at the neighborhood resolution and in relation to neighborhood-level emissions. In NYC's five counties, modeled NO_2 removed by the primarily-deciduous urban forest ranges from <1% (New York) to 13% (Richmond) of total emissions; modeled PM10 removal ranges from <4% (New York) to 20% (Richmond). Across a 900 m^2 grid, average traffic NO_2 emissions are over an order of magnitude greater than canopy removal; PM10 canopy removal slightly exceeds average traffic emissions. NO_2 and PM10 removal are weakly but significantly inversely correlated in space with traffic emissions at the grid level ($r = -0.126$, $p < 0.0001$). Land Use Regression modeling of monitored levels of NO_2 and PM2.5 reveals an inverse correlation with tree cover in winter (leaf-off) and summer (leaf-on) suggesting that canopy indicators represent lack of pollution sources rather than active pollution removal. Tree canopy deposition likely has at most a small impact on neighborhood air quality relative to emissions. Planners should emphasize a holistic view of the benefits of urban trees when prioritizing urban neighborhoods for tree planting.

1. Introduction

Interception of pollutants by the leaf surfaces of urban trees (McPherson et al., 1994; Beckett, Freer-Smith, & Taylor, 2000) is often used to justify large-scale tree planting programs across the United States. A comparison of the benefits of the tree canopies of several US cities reveals much variation in their pollution removal potential (Nowak, Crane, & Stevens, 2006), but no study has used a finer scale to look within a single urban area at variations at the neighborhood level. Because poor air quality leads to poor health, air quality improvements in high-risk areas are highly important

* Corresponding author. Tel.: +1 212 360 1496.
E-mail addresses: kristen.king@parks.nyc.gov (K.L. King), sjohnso5@health.nyc.gov (S. Johnson), ikheirbe@health.nyc.gov (I. Kheirbek), jacqueline.lu@parks.nyc.gov (J.W.T. Lu), tmatte@health.nyc.gov (T. Matte).
[1] Tel.: +1 212 788 1219.
[2] Tel.: +1 718 760 6597.

http://dx.doi.org/10.1016/j.landurbplan.2014.04.009

(US EPA, 2009, 2006). Given cities' increased investment in urban tree canopy as an infrastructural asset, it is important to understand the potential magnitude and limitations of tree planting as a strategy for improving neighborhood air quality.

The effectiveness of air pollution interventions can be measured by either tracking changes in emissions and deposition levels or changes in ambient pollution concentrations. An analysis of New York City's primarily deciduous urban forest using UFORE (now iTree Eco) at both a city- and county-wide level found that the entire urban forest removes 2202 tons of combined air pollutants per year (carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM_{10}), sulfur dioxide (SO_2)) (Nowak et al., 2007). A subsequent STRATUM (now iTree Streets) analysis modeled an inventory of nearly 600,000 street trees and determined that they intercept or absorb 272 tons of combined air pollutants annually and that street trees return approximately $5.60 in total benefits for every $1 spent on tree care (Peper et al., 2007). Both of these models use local weather and air pollution data in conjunction with field data measures to estimate pollution removal, as well as a gas-exchange deposition model for NO_2, SO_2, and O_3 and average deposition velocities from the literature for CO and PM_{10} removal (Nowak et al., 2008; Hirabayashi et al., 2014).

Modeling of ambient pollution levels using Land use Regression (LUR) that incorporates measures of undeveloped land such as open space, forest/natural area, or government land in proximity to air quality monitors has found that, in combination with density of emission sources, these measures successfully predict ambient levels of NO_2, black smoke, and fine particulate matter ($PM_{2.5}$), a component of PM_{10}, in New York City (Clougherty et al., 2013) and other municipalities (Gilbert, Goldberg, Beckerman, Brook, & Jerrett, 2005; Gulliver et al., 2011; Moore, Jerrett, Mack, & Kunzli, 2007; Sahsuvaroglu et al., 2006). In these models, increasing pollutant levels are associated with decreasing density of undeveloped land and increasing density of emission sources, such as traffic and development (often indicated by population density). LUR modeling of emission/deposition rates and ambient pollutant levels suggests that the benefits of urban trees coincide with areas of greatest canopy cover, but quantification of the extent of the effect requires tree size and species information. The provision of air quality benefits differs by species due to differences in leaf morphology and canopy structure that affect rates of particulate capture (Beckett et al., 2000).

While prior studies, including those in New York City, have estimated pollution removal potential at an urban scale, *intraurban* gradients in air pollution – which are due to varying density of local sources – are increasingly recognized as important contributors to population exposure, health effects, and environmental justice concerns. Furthermore, in New York City, neighborhoods have been prioritized for tree planting based in part on asthma prevalence as a strategy to reduce air pollution impacts on health (http://www.milliontreesnyc.org/html/about/getting_parks.shtml). We wanted to better understand the role of pollution removal by trees in New York City to meaningfully reduce exposure to in neighborhoods with greater air pollution concentrations associated with a greater density of emissions. To assess the potential for increased urban canopy to impact neighborhood level air pollution in NYC we used tree canopy cover data as well as inventories of tree species and size to geographically explore the relationship between canopy cover, estimated pollution removal potential, estimated emissions, and measured ambient air pollution levels in New York City neighborhoods. Specifically, we

1) Develop and compare modeled estimates of the spatial gradients of NO_2 and PM_{10} emissions with the pollution removal potential of the urban forest using street and park tree inventory data in the iTree Streets model at the county level and sub-county level at a 900 m^2 grid resolution. We hypothesize that the estimates of pollution deposition are exceeded by the extent of emissions and the ratio between the two will vary spatially across NYC.
2) Compared the role that tree cover, in combination with local pollution sources, plays in explaining the spatial variation of summertime (leaf-on) and wintertime (leaf-off) ambient black carbon (BC), nitrogen oxides, $PM_{2.5}$, and O_3 levels using monitoring data collected through the New York Community Air Survey (NYCCAS) (Matte et al., 2013) and modeled with LUR. Results from the first year of LUR modeling with NYCCAS data found that tree cover generated from high-spatial resolution aerial imagery is associated with decreased levels of BC, NO_2, $PM_{2.5}$, and O_3 in both the summer season and annual average models after controlling for other source indicators (New York City, 2011a; New York City, 2011b). We hypothesize that there will be greater effect estimates of the tree cover indicator in the leaf-on (summer) season as compared to the leaf-off (winter) season if pollution deposition by the tree canopy were driving the associations in the LUR models. If tree cover were simply representing areas with low levels of emission sources, then the effect estimates would be similar in leaf-on and leaf-off seasons.

2. Methods

2.1. Urban forest deposition estimation

The air quality benefits (deposition rates of NO_2 and PM_{10}) provided by New York City's urban forest were modeled using iTree Streets (v 4.0.3). In order to accomplish this, we compiled the most comprehensive tree inventory possible. Species and DBH of all trees in the public right-of-way was combined with park tree data when available, which resulted in over 650,000 individual trees contributing to the model results. This inventory is representative of the species distribution of the entire urban forest as it is primarily comprised of broadleaved deciduous trees. 99.1% of trees in the public right-of-way in NYC are deciduous (Peper et al., 2007), and the overall forest is estimated to be over 97% deciduous (Nowak et al., 2007). The ten most common species in NYC, which account for nearly 62% of all trees, are all broadleaf deciduous trees (Nowak et al., 2007).

This inventory is not comprehensive; it does not include data for any trees on private property and omits many park trees as well. Land cover datasets developed from high resolution aerial imagery gathered in 2001 and remote sensing using LiDAR in 2010 (USDA 2001, UVM 2010) provide comprehensive data for comparison. Both datasets were classified into land cover types that identified tree, shrub, and grass cover (MacFaden, O'Neil-Dunne, Royer, Lu, & Rundle, 2012; Myeong, Nowak, Hopkins, & Brock, 2001). The 2010 LiDAR dataset is assumed to be representative of "actual" tree canopy cover due to superior classification accuracy and currentness. Canopy extent modeling of the inventory data compared to the 2010 dataset reveals that our inventory underestimates actual present-day tree canopy by 51% on average across the five counties of NYC. We also expressed this underestimation at the level of each 900 m^2 grid cell (Fig. 1). For each of the scales of inquiry, we applied a correction factor to the model results in order to account for this underestimation. Because of this, tree canopy deposition rates are expressed as "adjusted canopy deposition rate."

2.2. Emissions estimation

County (borough)-level emissions estimates were calculated by summing nitrogen oxides (NO_x) and primary PM_{10} emissions estimates from point, area, non-road, and on-road sources in New York City from the 2005 US EPA National Emissions Inventory (NEI) (EPA 2011). In order to compare with the iTree Streets benefit