Making Rational Decisions About Air Pollution, Asthma and Urban Tree Planting

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1. Motivation

2. Conceptual model

3. Field observations
   Stochastic processes

4. Theoretical grounding
   Deterministic relationships

5. Application

6. Policy formulation?
Modeling Opportunities

1. What are the relative contributions of different sources to the PM load?

2. How does land use correlate with PM load?

3. How do trees affect PM load experienced by humans?

4. What are appropriate response metrics?
Motivation: Human health
Figure 1. Ecosystem-services framework based on the Millennium Ecosystem Assessment (MA 2003).
Reason for concern

Asthma Hospitalizations, 2004
Children age 0 to 14 years

- NATIONAL AVERAGE

RATE PER 1000 PEOPLE

Bronx
Brooklyn
Manhattan
Queens
Staten Island
New York City

Source: Centers for Disease Control; NYS Department of Health; analyzed by NYC Department of Health and Mental Hygiene

From: www.nyas.org/asthma 1/21/08
Urban Respiratory Health in Crisis

Community Health

Asthma is a significant problem for children in the community. Hospitalization rates for children aged 0-14 are 23.2%, exceeded in New York City only by East Harlem (which has a rate of 23.3%). There has been a rise in asthma, particularly among children—who are most vulnerable to developing asthma—that corresponds with a rise in asthma-causing pollution emissions due to energy production, fertilization and increased vehicle use. In New York City, asthma hospitalization rates almost doubled between 1988 and 1997, a change most strongly felt in the Bronx, where rates fully doubled during this period.
A potential solution............

Urban tree-planting reduces pollutants

Dear EarthTalk: Do urban trees really help reduce pollution and clean the air?

John Alderman, Washington, D.C.

In 1872, Frederick Law Olmsted, the granddaddy of American landscape architecture and the designer of New York's Central Park, proclaimed trees the "lungs of the city."

While Olmsted's statement may have been more philosophical than scientific, researchers have since found that city trees do indeed form important environmental functions like soaking up ground-level pollution and storing carbon dioxide, which helps offset global warming.

Each year in Chicago, for example, the windy city’s urban tree canopy removes 15 metric tons of carbon monoxide, 84 metric tons of sulfur dioxide, 89 tons of nitrogen dioxide, 191 metric tons of ozone and 212 metric tons of particulates, according to David Nowak, project leader of the U.S. Forest Service's Urban Forest Ecosystem Research Unit. Trees absorb these gaseous pollutants via the tiny pores in their leaves and break them down into less-harmful molecules during photosynthesis.

In Sacramento, Calif., a public-private partnership called Sacramento Shade spearheaded the planting of more than 200,000 trees around the city in the mid-1990s. In a study assessing Sacramento's bolstered tree cover, Greg McPherson of the Western Center for Urban Forest Research found that the region's urban forest removes more than 200,000 metric tons of carbon dioxide from the atmosphere each year, saving taxpayers as much as $3 million annually in pollution costs.

Meanwhile, the tree cover in New York City helps remove enough airborne toxins to save taxpayers as much as $10 million a year in pollution mitigation costs, according to Nowak.

The Big Apple’s five boroughs are home to more than five million trees, covering nearly 17 percent of its public and private land, he adds.

Gary Moll, a vice president at the nonprofit group American Forests, asserts that trees are the "ultimate urban multi-taskers, absorbing carbon dioxide and acting as filters, sponges, humidifiers, heat shields and wind blockers. Under Moll's supervision, American Forests is assessing the costs and benefits of tree cover across the country. The group uses a combination of satellite data, field surveys and computer modeling technology to measure regional tree canopy and calculate its dollar value.

All told, Olmsted was right in his assessment of the importance of city trees. Indeed, planting trees in urban environments may be one of the best medicines available to help restore our ailing cities.


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The over-built landscape of the South Bronx dominated by commercial and industrial land use
From the House version of the Climate Bill

The Congress finds that
(4) Shade trees have significant clean air benefits associated with them;

(5) Every 100 healthy trees removes about 300 pounds of air pollution (including particulates and ozone) and about 15 tons of carbon dioxide from the air each year;

(7) In over a dozen cities across the United States, increasing urban tree cover has generated between two and five dollars in savings for every dollar invested in such tree plantings
Conceptual Model
Figure 2. Framework for incorporating ecosystem services into improving environmental outcomes in cities. Both ecosystem services and disservices (benefits and costs of green space, respectively) must be identified for a given desired outcome. To quantify these services and disservices, we must further relate them to measurable supporting ecosystem processes.
Ecosystem services rendered by the urban forest

Regional

Local

Point sources

Mobile sources

Geological weathering, fire, agriculture

Urban landscape, deficient in ecosystem services

Ecosystem services rendered by the urban forest

Presumed Causal Chain

Asthma!

Respiratory health
Field Observations
Modeling Opportunities

1. What are the relative contributions of different sources to the PM load?

**Problems**
Stochastic variations in local and regional sources have different temporal scales

**Autocorrelations**

Existing samplers are biased against local sources
   Need for additional monitors?
   Need to correlate existing monitors with ground level monitors?
TEOM* samplers maintained by regulatory agencies are located on roof tops
Above level of near ground boundary layer
  Relatively well-mixed
  Less vulnerable to local variation
Less vulnerable to vandalism
Hourly averages: coarse time integral
* Tapered Element Oscillating Microbalance
Average [PM 2.5] for monitoring stations in NYC
PM2.5 events are spiky and stochastic
A hydrograph

A Koniograph

Fr. Greek, *konia*: soot or dust
Return Period, Street vs. Rooftop

Return Period, MS 201

Roof vs. Street w/o Rogue Event
Modeling Opportunities

2. How does land use correlate with PM load?

Problems
Distance from sources varies
   Wind modifies direction and severity of effect

Local variation in biophysical structure affects dispersion and mixing
   What is an appropriate typology to capture these effects?
   A priori or developed as part of the study?
Modeling Opportunities

3. How do trees affect PM load?

Problems
At least 2 processes occurring simultaneously
Deposition: removal from the air
Dispersion: rearranging where the PM occurs

Different particle sizes behave differently
Clean Air Act standards are based on aggregate size classes, PM 10 and PM2.5
NO current standards for ultrafine PM

Monitoring occurs on rooftops, where humans typically are not present
Case Study: The South Bronx
An over-built landscape dominated by commercial, industrial and warehouse land use. Heavy diesel truck burden.
Hypothesis: Particle concentration will decrease with distance from road source.
A *koniograph* of PM2.5 events: *spikey, stochastic*

Is there a story here?
Return Period: analogous to the 100 year storm. Summarizes, makes randomness informative.
Events frequency: 5m = curb < 10 m > 20,50,100m
You need to be 50 m back to be “decoupled” from street conditions
Deterministic Theory
For the dry deposition of 0.1 to 1.0 μm diameter particles, uncertainties of at least an order of magnitude exist even for their deposition to simple vegetative canopies (e.g., see Allen et al., 1991); greater uncertainties exist for forest canopies (e.g., see Peters and Eiden, 1992). For deposition of 0.1 to 1.0 μm diameter particles to the sea surface, no particle-size-dependent data appear to be available (e.g., see Rojas et al., 1993). Numerical studies have examined problems with modifying available dry deposition formulations for use in global models (e.g., Giorgi, 1988); the lack of mesoscale, particle-size-specific field studies for dry deposition to inhomogeneous vegetation and to the ocean results in at best
Accepted Theory

**Einstein- Stokes Relation**

\[ D = \frac{kT}{6 \pi \eta R} \]

**Fick’s 1st Law of Diffusion**

\[ J_j = -D_j \frac{\delta c_j}{\delta x} \]

- \( D \) = diffusivity
- \( K \) = Boltzmann constant
- \( \eta \) = viscosity
- \( R \) = particle radius

- \( J_j \) = flux (mol m\(^{-2}\) s\(^{-1}\))
- \( D_j \) = diffusion coefficient
- \( c_j \) = conc. (mol m\(^{-3}\))
- \( x \) = distance
Comparing particle behavior at extremes of PM2.5

**Extinction Plume, Ash 20 Branches**
Entire Chamber 2.0-3.0 µm

\[ b = 0.0270 \]

**Plume Extinction: Ash 20 Branches**
Entire Chamber, 0.3-0.4 µm

\[ b = 0.0134 \]
\( V_d \), **deposition velocity**: slope of Flux vs. ambient concentration

2.0-3.0 > 0.3-0.4, so at a given concentration, larger particles deposit faster than smaller particles. This **Contradicts Fick’s first Law**.
Can we model on a shaky theoretical foundation?
Response Metrics: Human Health Outcomes
SPECIAL ARTICLE

Fine-Particulate Air Pollution and Life Expectancy in the United States

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BACKGROUND

Exposure to fine-particulate air pollution has been associated with increased morbidity and mortality, suggesting that sustained reductions in pollution exposure should result in improved life expectancy. This study directly evaluated the changes in life expectancy associated with differential changes in fine particulate air pollution that occurred in the United States during the 1970s and 1990s.

METHODS

We compiled data on life expectancy, socioeconomic status, and demographic characteristics for 211 county units in the 51 U.S. metropolitan areas with matching data on fine-particulate air pollution for the late 1970s and early 1980s and late 1990s and early 2000s. Regression models were used to estimate the association between reductions in pollution and changes in life expectancy, with adjustment for changes in socioeconomic and demographic variables and in proxy indicators for the prevalence of cigarette smoking.

RESULTS

A decrease of 10 μg per cubic meter in the concentration of fine particulate matter was associated with an estimated increase in mean (±SE) life expectancy of 0.61 (0.20) year (P = 0.004). The estimated effect of reduced exposure to pollution on life expectancy was not highly sensitive to adjustment for changes in socioeconomic, demographic, or proxy variables for the prevalence of smoking or to the restriction of observations to relatively large counties. Reductions in air pollution accounted for as much as 15% of the overall increase in life expectancy in the study areas.

CONCLUSIONS

A reduction in exposure to ambient fine-particulate air pollution contributed to significant and measurable improvements in life expectancy in the United States.
For each 10µg m$^3$ increase in PM$_{2.5}$, life expectancy decreases by:

1978-1982  $\quad 0.46 \pm 0.22$ yr ($P=0.039$)
1997-2001  $\quad 0.37 \pm 0.20$ yr ($P=0.091$)

Children living in areas with more street trees have lower prevalence of asthma

G S Lovasi, J W Quinn, K M Neckerman, M S Perzanowski and A Rundle

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Updated information and services can be found at:
http://jech.bmj.com/cgi/content/full/62/7/647

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Notes
RESULTS
Street tree density was high in the most densely populated areas and in areas with less poverty, and was negatively correlated with the two measures of asthma burden (table 1). Higher street tree density was associated with a lower prevalence of childhood asthma even after adjustment for potential confounders (including sociodemographic characteristics, population density and proximity to pollution sources), but the association between street trees and hospitalisations as a result of asthma was no longer significant after adjustment.

Unadjusted estimates suggest that an increase in tree density of 1 standard deviation (SD, 343 trees/km²) would be associated with a 24% lower prevalence of asthma (relative risk (RR), 0.76 per SD of tree density; 95% CI, 0.67 to 0.91) and a 26% lower risk of hospitalisation as a result of asthma (RR, 0.74 per SD of tree density; 95% CI, 0.62 to 0.87). After adjustment for potential confounders, we estimate that the same increase in street tree density would be associated with a 29% lower early childhood prevalence of asthma (RR, 0.71 per SD of tree density; 95% CI, 0.64 to 0.79). The association between tree density and hospitalisations as a result of asthma was not significant after adjustment (RR, 0.89 per SD of tree density; 95% CI, 0.75 to 1.06).

and proximity to sources of air pollution. The inverse association of street trees with hospitalisations for childhood asthma became non-significant following adjustment for the same potential confounders.

Our cross-sectional and ecological study does not permit inference that trees are causally related to the prevalence of childhood asthma at the individual level. These observational data may be subject to residual confounding or confounding by unmeasured characteristics. Previous studies of tree density and childhood asthma have not been published to our knowledge, and our results need to be replicated by others. Future studies may be more robust if they are able to measure and control for characteristics of the home environment, such as the presence of allergens.

A natural experiment could demonstrate whether abundant street trees caused the lower prevalence of asthma observed in densely planted areas. The PlaNYC sustainability initiative (www.nyc.gov/html/planyc2030) includes a commitment to plant one million trees in New York City by the year 2017 and offers an opportunity for a large prospective evaluation. Staged tree planting by area could help identify the effects of increased tree density on childhood asthma.
An alternative, reductionistic approach
Collect particles in the field
Current Application: Monitoring the Effect of Peak Power Generators on Environmental Justice Communities (NYSERDA RFP)
Coal fired peaking power plants

Gowanus, Brooklyn, NYC
Determining Impact of Emissions on Environmental Justice (EJ) Communities

1. Where should sensors be placed?

2. How many sensors are needed?

3. How long should sensors be deployed?
Policy Implications?
COUPLED BIOGEOCHEMICAL CYCLES

Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions

Diane E Pataki1,2*, Margaret M Carreiro3, Jennifer Cherrier4, Nancy E Grulke5, Viniece Jennings6, Stephanie Pincetl7, Richard V Pouyat8, Thomas H Whitlow9, and Wayne C Zipperer8

Urban green space is purported to offset greenhouse-gas (GHG) emissions, remove air and water pollutants, cool local climate, and improve public health. To use these services, municipalities have focused efforts on designing and implementing ecosystem-services-based “green infrastructure” in urban environments. In some cases the environmental benefits of this infrastructure have been well documented, but they are often unclear, unquantified, and/or outweighed by potential costs. Quantifying biogeochemical processes in urban green infrastructure can improve our understanding of urban ecosystem services and disservices (negative or unintended consequences) resulting from designed urban green spaces. Here we propose a framework to integrate biogeochemical processes into designing, implementing, and evaluating the net effectiveness of green infrastructure, and provide examples for GHG mitigation, stormwater runoff mitigation, and improvements in air quality and health.

Panel 1. Urban trees and air quality

Section 205 of HR2454, The American Clean Energy and Security Act of 2009, states:

The Congress finds that:
(4) shade trees have significant clean air benefits associated with them;
(5) every 100 healthy trees removes about 300 pounds of air pollution (including particulate matter and ozone) and about 15 tons of carbon dioxide from the air each year;
(7) in over a dozen test cities across the United States, increasing urban tree cover has generated between two and five dollars in savings for every dollar invested in such tree plantings (www.grotrack.us/congress/bill.xpd?bill=h111-2454).

One would assume from this text that (1) our knowledge of the impacts of trees on air quality is adequate to formulate “good” policy and (2) trees appreciably reduce concentrations of harmful air pollutants. However, despite simulation models demonstrating the benefits of urban trees, their effects on air pollution remain empirically unquantified.

One of the presumed benefits of trees is particulate matter (PM) deposition onto canopies, which have a large surface area. However, particle deposition is affected by particle size, landscape roughness, canopy and leaf characteristics, and atmospheric turbulence. This complexity has hampered the development of a coherent theory for particulate deposition in canopies (Grantz et al. 2003; Hicks 2008). Reports of particulate deposition tend to be based on assumptions, models, or theories that are untested in urban settings. It is unlikely that even optimistic estimates of pollutant removals (uptake and deposition) will appreciably affect atmospheric concentrations in polluted cities. In contrast, tree canopies may reduce dispersion, causing locally elevated PM concentrations.

A commonly used model, Urban Forest Effects (UFORE) Model (www.ufore.org), estimates the effects of urban trees on particulate pollution. For New York City (NYC), UFORE predicted that -- during the growing season -- the forest removes 0.47% of PM matter, based on reported deposition velocities for particulates less than 10 microns in diameter (PM₁₀) (Nowak et al. 2002). If NYC were to add 1 million new trees to the urban forest, as is currently proposed (www.milliontreesnyc.org), particulate pollution removal would increase to 0.55% of PM₁₀ (there are currently ~6 million trees in the five-borough area). Thus, the additional 1 million trees would reduce PM by 0.02891 μg m⁻³ to achieve a concentration of 36.97 μg m⁻³. A decrease in PM₂.5 by 10 μg m⁻³ has been estimated to add 0.61 years to human life expectancy (Pope et al. 2009). The net effect of planting 1 million trees would be to add 4.05 hours to the lives of NYC residents, based on PM reductions alone.

Although based on many assumptions, these calculations illustrate that assertions of the specific physical benefits of urban trees can be overstated. The pitfall in doing so is that the public receives the wrong message about how critical environmental and human-health problems must be solved. Tree-planting programs clearly have many benefits, but it is incumbent upon scientists to provide accurate and realistic estimates of both the ecosystem services and disservices of such programs.
What roles can Computational Sustainability in the complex arena?
MILLIONTREESNYC, GREEN INFRASTRUCTURE, AND URBAN ECOLOGY: BUILDING A RESEARCH AGENDA

Report from the Workshop

MillionTreesNYC Advisory Board Research & Evaluation Subcommittee