Fine Particulate Matter and Polycyclic Aromatic Hydrocarbon Concentration Patterns in Roxbury, Massachusetts: A Community-Based GIS Analysis

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Given an elevated prevalence of respiratory disease and density of pollution sources, residents of Roxbury, Massachusetts, have been interested in better understanding their exposures to air pollution. To determine whether local transportation sources contribute significantly to exposures, we conducted a community-based pilot investigation to measure concentrations of fine particulate matter (particulate matter < 2.5 µm; $PM_{2.5}$) and particle-bound polycyclic aromatic hydrocarbons (PAHs) in Roxbury in the summer of 1999. Community members carried portable monitors on the streets in a 1-mile radius around a large bus terminal to create a geographic information system (GIS) map of concentrations and gathered data on site characteristics that could predict ambient concentrations. Both $PM_{2.5}$ and PAH concentrations were greater during morning rush hours and on weekdays. In linear mixed-effects regressions controlling for temporal autocorrelation, PAH concentrations were significantly higher with closer proximity to the bus terminal ($p < 0.05$), and both pollutants were elevated, but not statistically significantly so, on bus routes. Regressions on a subset of measurements for which detailed site characteristics were gathered showed higher concentrations of both pollutants on roads reported to have heavy bus traffic. Although a more comprehensive monitoring protocol would be needed to develop robust predictive functions for air pollution, our study demonstrates that pollution patterns in an urban area can be characterized with limited monitoring equipment and that university–community partnerships can yield relevant exposure information. *Key words*: community-based research, fine particulate matter, geographic information system, personal exposure, polycyclic aromatic hydrocarbons, transportation. *Environ Health Perspect* 109:341–347 (2001). [Online 8 March 2001]
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As in many urban areas, residents in the Dudley Square area of Roxbury, Massachusetts (a neighborhood in Boston) have become increasingly concerned about respiratory health in their community. The prevalence of asthma in the United States has risen substantially over the past 20 years in all regions of the country (*1*), with rates within inner-city communities generally higher than rates elsewhere (*2–6*).

These general patterns have been found within the Boston area. A recent analysis (*7*) found that asthma hospitalization rates were far greater in Roxbury (9.8 hospitalizations per 1,000 people) than in Boston or in Massachusetts as a whole (4.2 and 2.1, respectively). In a cross-sectional analysis of Boston families, asthma prevalence was higher for families of lower socioeconomic status, with children 7.6 times more likely to have asthma [95% confidence interval (CI), 2.4–23.5] if they lived in zip codes with 20% of the population below the poverty level than in zip codes with less than 10% of the population below the poverty level (*8*). Although the areas of residence were not identified in the study, all zip codes in Roxbury fall within the higher poverty category. In addition, a small-scale survey by youth interns with the Roxbury Environmental Empowerment Project (REEP) found an asthma prevalence of 24% in Dudley Square (*9*).

Although the development and exacerbation of respiratory disease are multifactorial and complex, there is evidence of links between traffic and adverse respiratory outcomes. In recent studies, lung function (*10,11*), respiratory symptoms (*10,12*), medical care visits for asthma (*13*), and hospital admissions for asthma (*14*) were all associated with high traffic flow and proximity to main roads. Although these studies could not attribute respiratory symptoms to specific pollutants, other standard epidemiologic analyses have linked particulate matter and other transportation-related pollutants to a variety of health outcomes (*15–17*). Other research has shown that pollen particles can bind with diesel exhaust to ease their passage into the deep pockets of the lungs (*18,19*) and that pollen and other allergens are prominently found in road dust (*20*). Particle-bound polycyclic aromatic hydrocarbons (PAHs), a constituent of diesel exhaust, have been evaluated as potential carcinogens and mutagens (*21,22*) and have been shown to influence the immune system, potentially precipitating development of disease (*23*).

For residents of Dudley Square, the aforementioned survey by local schoolchildren found that traffic was perceived as the primary source of air pollution in the community (*9*). This is unsurprising, given the traffic density in the neighborhood and the visibility of the pollution sources. Dudley Square once housed an elevated train station, but this station was converted to a major bus terminal and transportation hub when the train was rerouted and the elevated tracks were removed in the 1980s. A recent survey by Alternatives for Community and Environment (ACE) found that 15 bus and truck depots are located within a 1.5-mile radius of Dudley Square, garaging more than 1,150 diesel vehicles, including approximately one-half of the Massachusetts Bay Transportation Authority bus fleet (*24*).

Through meetings with neighborhood groups and survey findings, ACE determined that air pollution from traffic was a major concern of residents, largely because of the perceived link with asthma and other respiratory diseases. To help residents of Dudley Square determine the air pollution patterns in their neighborhood and to evaluate the potential contributions of diesel buses and other vehicles, researchers from the Harvard School of Public Health (HSPH) collaborated with ACE on a pilot modeling project. Previously, the HSPH and ACE had collaborated on efforts that led to the siting of a fine particulate matter monitor in Dudley Square and the development of the AirBeat real-time air quality information network for Roxbury.

The goal of our analysis was to construct a study design that would allow us to characterize pollution patterns in Dudley Square in a manner that was both scientifically valid

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and responsive to community interests. The ultimate goal of our methodological framework was to begin to develop an approach applicable for epidemiologic assessments of traffic-related respiratory symptoms that would allow us to estimate personal exposure and determine the role of specific pollutants or sources. Thus, to evaluate spatial and temporal patterns in transportation-related pollutants in Dudley Square, we continuously measured both particulate matter < 2.5 µm ($PM_{2.5}$; fine particulate matter) and PAHs throughout the neighborhood and mapped the concentrations to create a visual representation of pollution patterns. We collected site characteristics to develop predictive regression functions for air pollution concentrations. To ensure that the project was integrated into the community beyond the project origination, we developed the study design in concert with a community-based organization, involved local high school students in the air pollution monitoring, and discussed findings at Roxbury-based conferences and meetings.

Methods

Study design. To characterize spatial and temporal patterns in air pollution concentrations over a defined area, a geographic information system (GIS) approach was required. Ideally, this would involve a relatively dense network of monitors placed in randomly selected and representative locations, with site-specific information gathered at each location. This approach was used recently in Europe (*25*), where NO_2 concentrations were estimated at 80 fixed monitoring sites around an urban center with regression models developed to determine factors that predict concentrations.

However, our pilot project had limited sampling instruments available (two for PAHs and one for $PM_{2.5}$), so fixed-site monitoring would not sufficiently cover the neighborhood. To capture the range of street configurations and source distributions, we opted to carry the portable monitors throughout the neighborhood, placing the additional PAH monitor at a fixed, central location. By covering the same locations multiple times at different times of the day, we were able to calculate concentration patterns that represented spatial rather than simply temporal variability, while estimating covariate effects in enough different settings to strengthen our confidence in our regression findings.

Monitoring protocol. In July and August 1999, we took continuous measurements of concentrations of $PM_{2.5}$ and particle-bound PAHs in the area surrounding the Dudley Square bus terminal. We measured particle-bound PAH concentrations using a PAS 2000CE (EcoChem Analytics, League City, TX), a photoelectrical aerosol sensor that uses an irradiation energy and lamp wavelength that are specific to PAHs. This methodology has been found to correlate well with conventional integrated measurements (*26*). We measured $PM_{2.5}$ concentrations using a DustTrak 8520 (TSI, Minneapolis, MN), a laser photometer fitted with an impactor to measure particles between 0.1 and 2.5 µm. One-minute average concentrations of both pollutants were continuously recorded. The DustTrak was calibrated to a zero filter during sampling and to A1 test dust in the year before use, and the PAS 2000CE was factory calibrated before use. Along with concentration measures, temperature and relative humidity were also continuously recorded using HOBOs (Onset Computer Corporation, Bourne, MA).

It should be noted that DustTrak $PM_{2.5}$ concentrations have been shown to be approximately twice as high as concentrations from mass-based reference methods (*27*). This has been explained by the use of artificial aerosols for DustTrak calibration, which may have different characteristics (in terms of shape, size, density, and refractive index) than actual urban particles. Although the methods measure different concentrations, they are well correlated (*27*). Our measurements with colocated DustTraks and tapered element oscillating microbalances (TEOM; not during the period of this study) similarly found a strong correlation but a consistent factor of 2–3 difference between the methods. Thus, the DustTrak $PM_{2.5}$ measurements should not be interpreted as the actual levels in Dudley Square, but the strong correlations with reference methods indicates that our statistical analysis is not affected by this issue.

We took simultaneous environmental and meteorologic measurements at both fixed and mobile sites. The fixed-site PAH monitor was placed in the second story of an office building overlooking the Dudley Square bus terminal to represent local concentrations and exposures. PAH concentrations were continuously measured at this fixed site for the entire sampling period. In addition, given a lack of fixed-site $PM_{2.5}$ data due to instrument limitations, we used data gathered by other researchers using a TEOM situated in Dudley Square (*28*).

Mobile measurements of both PAHs and $PM_{2.5}$ were taken during the morning hours (approximately 0700–1100 hr) by students from the Boston Evening Academy (BEA), an alternative academic program within the Boston Public School system that serves high school students who are over-age for their grade level, are parenting, or who have other personal needs that limit conventional high school attendance. Students were trained by HSPH staff, and teachers from the BEA provided additional supervision and contributed educational content.

For the mobile measurements, BEA students traced paths within a 1-mile radius of Dudley Square, recording their locations every 5 min. Both large and small streets were covered, establishing a comprehensive pollution map of the area. In addition, approximately every 30 min, the students recorded detailed characteristics of their surroundings, including qualitative estimates of the number of lanes for the closest street, car and bus density, road quality, and land use. Wind speed and direction were only qualitatively estimated for a subset of measurements and were not included in the analysis. All data collected were geocoded in ArcView (ESRI, Redlands, CA).

In addition to the subset of qualitative parameters above, data were gathered to represent the frequency of bus activity on the road and the general level of traffic on the road. We determined the presence or absence of bus lines on a given street from Massachusetts Bay Transportation Authority (MBTA) route maps and schedules. Although this strategy could not incorporate paths traveled by buses not in service or by non-MBTA buses, it provided a reasonable proxy for the presence of city buses. We also collected information on the frequency of bus activity on these streets, defined as the average number of buses scheduled per hour during the morning hours on a given road. For bus lines that were scheduled every 10 min or less, rather than at defined times, we assumed that the buses were spaced 10 min apart.

We also gathered information on the road classification for all roads covered by the mobile measurements as a proxy for the overall volume of traffic. This information was extracted from U.S. Census TIGER data for Suffolk County, Massachusetts. Roads were categorized as A35 (connecting road, divided), A41 (neighborhood roads, city streets, and unimproved roads, undivided), and A45 (neighborhood roads, city streets, and unimproved roads, divided). Our underlying assumption was that A35 roads would have the highest volume of traffic. A small number of measurements were taken within parks, which were not placed in any road category.

Finally, to test whether a concentration gradient existed from the Dudley Square bus terminal, we used ArcView to estimate the distance between each mobile measurement and this hypothesized fixed source. In addition, to evaluate other potential concentrated emission sources, we gathered information on the locations of all parking facilities in the Dudley Square area. Two facilities were selected as potential contributors to local air pollution based on the number of parking spaces, the amount of activity in the lots, and the types of vehicles: the MBTA Bartlett garage and the National School Bus lot. The sites of the hypothesized sources, along with the monitor locations and the dates of mobile monitoring, are presented in Figure 1.

Statistical methods. To determine the significance of site characteristics anticipated to predict ambient concentrations, we used a regression-based approach. Because we were comparing sequential 1-min average concentrations, it was anticipated that the measured concentrations would be highly spatially and temporally correlated with one another. Statistical methods that assume independence of observations (such as ordinary least squares) would therefore be likely to overstate the significance of predictive factors.

Although data from our study incorporate both spatial and temporal variability, our study design makes them difficult to distinguish from one another. Our approach was to use empirical methods to evaluate whether the evidence was stronger for temporal or spatial correlation. We then used the chosen covariance model for our baseline analysis and applied the alternative model as well to test whether our findings were sensitive to the assumed correlation structure.

Semivariograms for both $PM_{2.5}$ and PAHs revealed a clearer pattern of temporal correlation than of spatial correlation. Consequently, we favored a covariance model that adjusted only for temporal (AR-1) autocorrelation at the expense of spatial autocorrelation. Thus, within our primary regression analysis, we controlled for autocorrelation by applying linear mixed-effects (LME) models using an AR-1 autoregressive correlation structure within each day of measurements (*29*). However, to validate the results from our AR-1 model, we also fit a Gaussian spatial model. A Gaussian model assumes that the covariance between two measurements is proportional to $exp(-d^2/\rho^2)$, where d is the distance between the points where the measurements were collected and ρ is a correlation parameter to be estimated. This model implies that the covariance will decrease as the distance between points increases. Both the spatial and temporal models were fit using PROC MIXED of SAS software (SAS Institute, Cary, NC).

In all regression models, air pollution measures were log-transformed, given a relatively lognormal distribution of concentrations for both pollutants. However, we present arithmetic means and standard deviations within our descriptive statistics for comparability with air pollution standards and other exposure assessments.

Results

Summary of findings. For the fixed-site monitor, the mean particle-bound PAH concentration was 9 ng/m^3, with significant variability in 1-min average concentrations (SD = 26). For 1-hr average concentrations, the standard deviation was reduced to 8. For the hours between 0700 hr and 1100 hr (when mobile measurements were also collected), the mean fixed-site PAH concentration was 16 ng/m^3. In contrast, for 1-min average measurements from the mobile monitor, the mean PAH concentration was 29 ng/m^3 (SD = 54). These data provide some evidence of both spatial and temporal variability in Dudley Square.

For mobile measurements of $PM_{2.5}$, the mean concentration was 49 µg/m^3 (SD = 65). Although we did not collect comparable fixed-site $PM_{2.5}$ data due to instrument limitations, we used TEOM data gathered by other researchers in Dudley Square to provide a concentration estimate (*28*). For the dates and times of our mobile monitoring, the mean $PM_{2.5}$ concentration measured by TEOM was 15 µg/m^3 (SD = 12). As

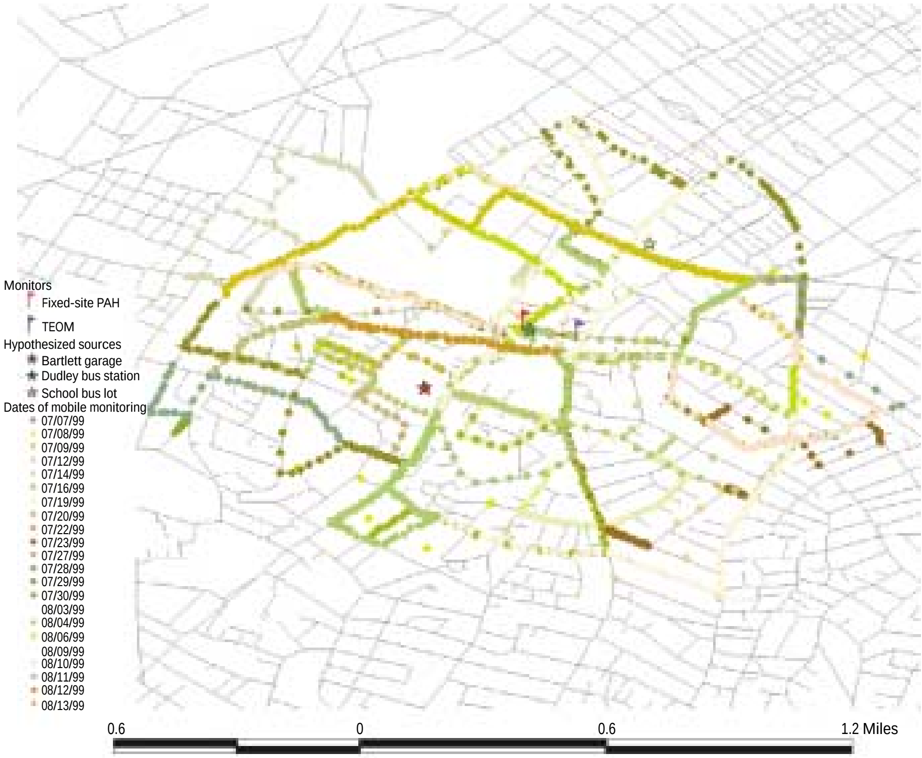

Figure 1. Map of monitoring strategy. DustTrak ($PM_{2.5}$) and PAS 2000CE (PAH) were used for mobile monitoring between 0700 hr and 1100 hr on specified dates, with fixed-site measurements (PAS 2000CE for PAH and TEOM for $PM_{2.5}$) taken 24 hr/day throughout sampling period. Note that many locations were covered multiple times by mobile monitoring, and only the latest date is visible on the map.

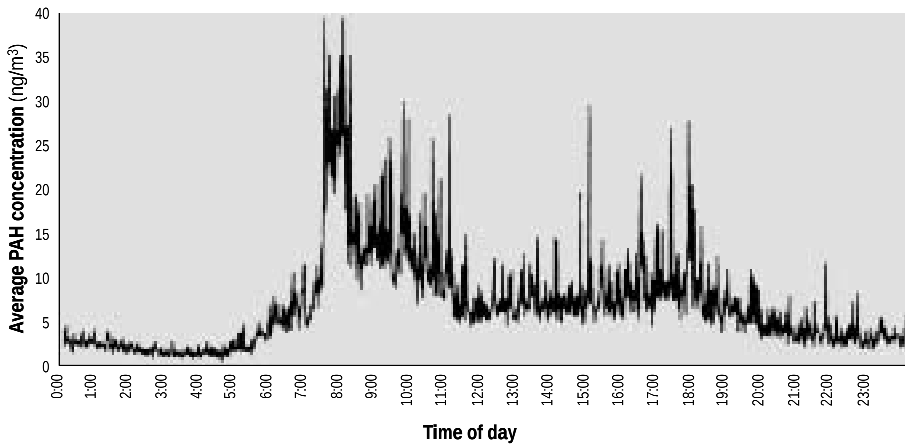

Figure 2. Diurnal variability in fixed-site, 1-min average PAH concentrations near Dudley Square, averaged across sampling days in July/August 1999 (ng/m^3).

expected, the 1-hr average concentrations with the TEOM and DustTrak differed significantly in magnitude but were reasonably well correlated ($r = 0.84$), indicating that the DustTrak measurements were appropriate for predictive regression modeling.

To demonstrate temporal trends in the data without confounding by location, we focus on PAH concentrations measured at the fixed monitoring site. PAH concentrations showed significant diurnal variability over the course of the sampling period, with the highest concentrations generally corresponding to the morning and evening rush hours and minimal concentrations during low-traffic hours (Figure 2). In addition, there was evidence of a weekly trend, with mean concentrations consistently lower on weekends than on weekdays (Figure 3). Figure 3 also contains the mobile monitor concentrations to illustrate the systematically higher concentrations measured with mobile monitors (related to both time of measurement and source proximity). Both of these figures provide some support for the hypothesis that transportation sources contribute to local PAH concentrations. Similarly, fixed-site $PM_{2.5}$ concentrations measured by TEOM had the highest mean concentrations at 0700 hr and 0800 hr, supporting the hypothesized effects of morning rush hour.

To illustrate spatial variability in the data, we present the concentrations of particle-bound PAHs (Figure 4) and $PM_{2.5}$ (Figure 5) in a GIS format, averaged across all sample times and across small geographic cells. There was significant spatial/temporal variability across the Dudley Square neighborhood, with cell-averaged PAH concentrations ranging between 0.3 and 340 ng/m^3 and cell-averaged $PM_{2.5}$ concentrations ranging between 2 and 347 µg/m^3. It should be noted that these estimates reflect 1-min average measurements, and variability would be reduced somewhat with longer averaging times.

Regression modeling. To evaluate whether 1-min average PAH or $PM_{2.5}$ concentrations could be predicted by site or activity characteristics, we applied an LME regression to these data assuming temporal autocorrelation. The covariates evaluated included the three parameters collected for all measurements (presence/absence of a bus route, road type, and distance from Dudley Square), along with temperature and relative humidity. Preliminary univariate and multivariate regressions using the three hypothesized fixed sources demonstrated that distance from the bus terminal was the strongest distance parameter, and therefore the two parking facility terms (which are highly correlated with distance from the bus terminal) were omitted from subsequent models.

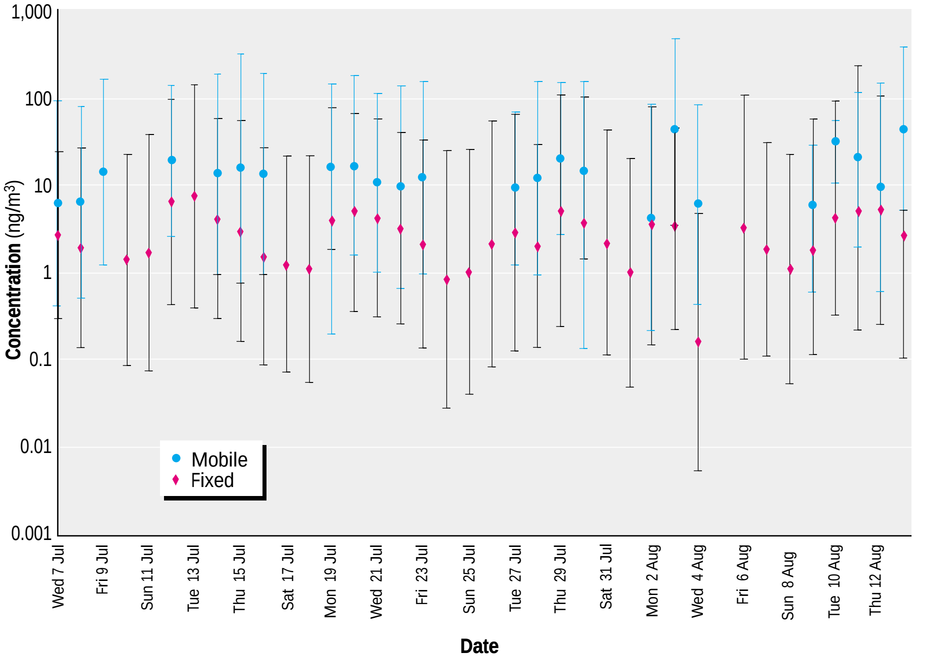

Figure 3. Daily concentration distributions of PAHs from a fixed-site monitor in Dudley Square (24-hr measurements) and from a mobile monitor (0700–1100 hr) in July/August 1999 (ng/m^3).

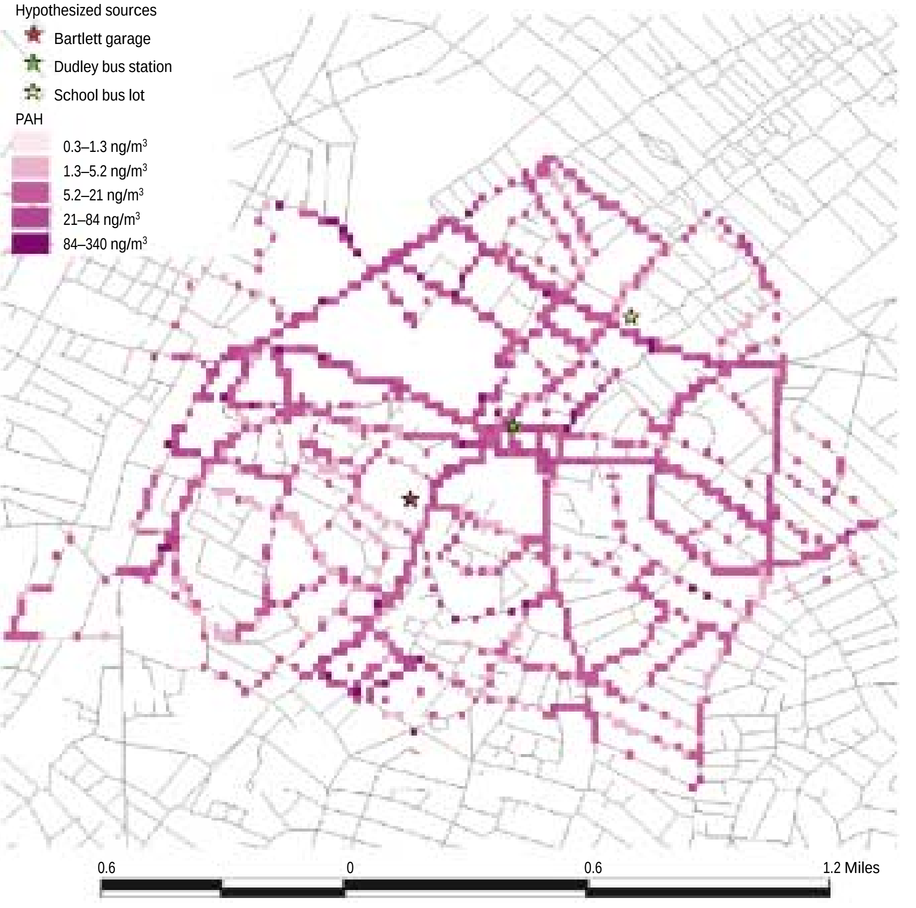

Figure 4. GIS representation of cell-averaged, 1-min average PAH concentrations near Dudley Square, derived from mobile PAS 2000CE monitoring in July/August 1999 (ng/m^3).

In our baseline regression, PAH concentrations were significantly higher closer to the bus terminal and with higher relative humidity ($p < 0.05$; Table 1). Concentrations were also higher on higher-traffic connecting roads and on bus routes, but not significantly so. For $PM_{2.5}$, only temperature and relative humidity were statistically significant terms, although there was a trend toward higher concentrations on bus routes and closer to the terminal (Table 2). The site parameters remained statistically insignificant terms in the model even with the exclusion of temperature and relative humidity. For both pollutants, estimated frequency of buses was a poorer predictor than presence/absence of a bus line.

In our Gaussian spatial model for PAHs, concentrations were significantly greater on bus routes, in closer proximity to the bus terminal, and with higher relative humidity. For $PM_{2.5}$, relative humidity was the only statistically significant predictor ($p < 0.05$). Thus, the primary difference between the temporal model and the spatial model is that the spatial model shows that bus routes are significant predictors of PAH concentrations, whereas the temporal model shows the bus route term to be insignificant. Our choice of the temporal model, justified by semivariograms, is therefore a somewhat conservative one. Both models support the conclusions that PAH concentrations are greater closer to the bus terminal, that concentrations of both pollutants are higher (with varying significance) on bus routes, and that site characteristics are not significant predictors of $PM_{2.5}$ concentrations.

To evaluate other potential predictors, we also regressed 10-min average concentrations on the recorded site characteristics during these measurement periods, although most parameters could not be quantified and the sample size is relatively small ($n = 73$ for PAHs, $n = 67$ for $PM_{2.5}$). We did not include road class or presence/absence of bus route, since those terms were theoretically superseded by more precise variables such as the number of lanes and the density of bus traffic during the observation period. For PAHs, concentrations were significantly higher on roads with heavier bus traffic (Table 3). For $PM_{2.5}$, concentrations were higher (but not significantly so) on roads with heavy bus traffic, as well as with greater temperature and relative humidity (Table 4).

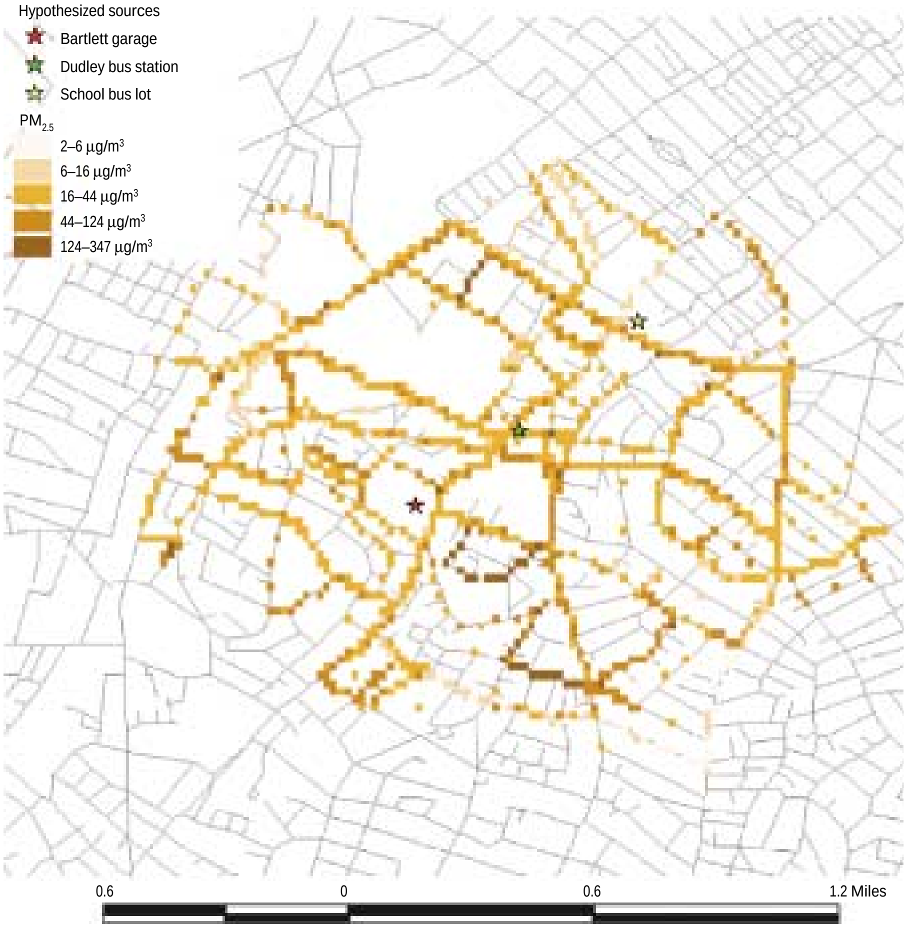

Figure 5. GIS representation of cell-averaged, 1-min average $PM_{2.5}$ concentrations near Dudley Square, derived from mobile DustTrak monitoring in July/August 1999 (µg/m^3).

Table 1. LME regression model of 1-min average PAH concentrations (ng/m^3) in Roxbury in July/August 1999, derived from PAS 2000CE mobile monitoring (n = 3,667).

Variable	Estimate	SE	*p*-Value
Intercept	1.02	0.28	0.002
On bus route	0.034	0.019	0.08
Road class			
A35	0.18	0.40	0.23
A41	0.07	0.13	0.58
A45	0.04	0.14	0.76
Park	0.00	0.00	—
Miles from bus station	–0.30	0.07	< 0.0001
Temperature (°F)	–0.0022	0.0027	0.41
Relative humidity (%)	0.0062	0.0013	< 0.0001

Discussion

Our analysis demonstrated that significant spatial and temporal variability in air pollution concentrations can be found in a small geographic area (approximately a 1.5-mile diameter), with evidence that local traffic patterns played an important role. Because the study was designed to address the concerns of the community, we interpret our findings in light of the questions that concerned community members.

Residents of Dudley Square were concerned about whether air pollution significantly affected their health and whether this could be attributed to diesel buses and other traffic. We did not gather the health data necessary to evaluate the first question, but we can make some comparisons with air quality standards and past exposure assessments. For $PM_{2.5}$, mobile DustTrak measurements (mean of 49 µg/m^3) were quite high compared to expected background levels, but much of this discrepancy is likely a function of instrumentation. Focusing on the fixed-site TEOM measurements, the mean $PM_{2.5}$ concentration across all sampling days (19 µg/m^3) did exceed both the U.S. Environmental Protection Agency's proposed annual standard and the mean concentration from a sampling location approximately 1 mile from Dudley Square (15 mg/m^3 for both) (*28*). If $PM_{2.5}$ concentrations were similar for other times of the year, this might imply that the local sources in Dudley Square could contribute incremental concentrations that would lead to violations of the proposed $PM_{2.5}$ annual standard.

For particle-bound PAHs, ambient air quality standards are not available, so we must rely on comparisons with other studies. This is made difficult by the large number of chemical constituents in the category of PAHs and differences in study goals. Because our ultimate goal was to characterize spatial and temporal patterns in an ambient environment, we selected a monitor that was lightweight and relatively sensitive. A recent study in different neighborhoods in the Boston area also used a photoelectrical PAH monitor, although a different monitor was used than in our study and measurements were taken indoors (*30*). Mean concentrations associated with outdoor sources were estimated to be 39 ng/m^3 (SD = 25) on weekdays in a building adjacent to a six-lane highway, with a lower concentration of 26 ng/m^3 (SD = 25) in a semi-urban location in close proximity to highways and traffic thoroughfares. These concentrations are similar to levels measured by our mobile monitor (mean of 29 ng/m^3) and are somewhat higher than levels measured by our fixed monitor (mean of 9 ng/m^3).

Past measurements of carcinogenic PAHs might also be comparable to our measurements, as this parameter roughly corresponds to the PAHs that will adhere to particles. According to a summary article (*31*), average outdoor concentrations ranged between 0.2 and 3.0 ng/m^3 in the Great Lakes region, with values as high as 15 ng/m^3 and 50 ng/m^3 in highly urbanized areas of Las Vegas, Nevada, and Denver, Colorado, respectively. Our findings appear similar to levels measured in other highly urbanized cities.

On the question of source attribution, we did not find a statistically significant effect of many site characteristics on $PM_{2.5}$ concentrations, potentially supporting the concept of fine particulate matter as a regional pollutant driven by secondary sulfates in the northeastern United States. This is in agreement with the findings of a recent study at busy intersections in Harlem, New York (*32*). However, there was weak evidence of elevated $PM_{2.5}$ concentrations in the vicinity of diesel buses, which would be expected to emit substantial quantities of fine particles. These divergent findings can be reconciled by the fact that short averaging times were used in our study and ambient monitors are often not placed at ground level in transportation "hot spots." Limitations in our predictive variables could also explain the lack of statistical significance. For example, road class is a relatively poor proxy for traffic density, and the presence/absence of a bus route on a given road may not precisely reflect the magnitude of diesel-related traffic (from MBTA buses and other vehicles).

In addition, the diurnal and weekly variability in PAH concentrations, along with the significance of bus-related parameters in regression models, provide evidence that local transportation sources are a major source of ambient PAH exposure for the residents of this neighborhood. Further investigation would be needed to determine the significance of these air exposures when compared with exposures from food, which were shown to account for more than 96% of median daily carcinogenic PAH intake in the Total Human Environmental Exposure Study (*31*).

Despite the evidence of temporal and spatial variability and some influence of bus traffic on concentrations, our pilot investigation had some limitations in its ability to provide definitive information to residents. Because of the size of the sampling area and the limited sampling period, it was impossible to measure

Table 2. LME regression model of 1-min average $PM_{2.5}$ concentrations (mg/m^3) in Roxbury in July/August 1999, derived from DustTrak mobile monitoring (n = 3,089).

Variable	Estimate	SE	*p*-Value
Intercept	–2.99	0.22	< 0.0001
On bus route	0.0087	0.0086	0.31
Road class			
A35	–0.10	0.063	0.13
A41	–0.11	0.060	0.09
A45	–0.10	0.063	0.12
Park	0.00	0.00	—
Miles from bus station	–0.047	0.061	0.43
Temperature (°F)	0.013	0.0022	< 0.0001
Relative humidity (%)	0.012	0.0015	< 0.0001

Table 3. LME regression model of 10-min average PAH concentrations (ng/m^3) in Roxbury in July/August 1999, using PAS 2000CE mobile monitoring for the subset of 10-min periods with detailed site characteristic data (n = 73).

Variable	Estimate	SE	*p*-Value
Intercept	1.48	0.85	0.10
Number of lanes	0.006	0.037	0.87
Car traffic			
Very heavy	–0.022	0.16	0.89
Heavy	–0.021	0.13	0.87
Light	0.071	0.14	0.63
Very light	0.00	0.00	—
Bus traffic			
Very heavy	0.55	0.15	0.0015
Heavy	0.48	0.15	0.003
Light	0.14	0.13	0.26
Very light	0.00	0.00	—
Road surface			
Good	–0.002	0.28	0.99
Fair	–0.15	0.29	0.63
Poor	0.00	0.00	—
Temperature (°F)	–0.0090	0.008	0.27
Relative humidity (%)	0.0069	0.0043	0.11

Table 4. LME regression model of 10-min average $PM_{2.5}$ concentrations (mg/m^3) in Roxbury in July/August 1999, using DustTrak mobile monitoring for the subset of 10-min periods with detailed site characteristic data (n = 67).

Variable	Estimate	SE	*p*-Value
Intercept	–2.82	0.55	< 0.0001
Number of lanes	–0.016	0.021	0.45
Car traffic			
Very heavy	–0.025	0.089	0.78
Heavy	–0.043	0.069	0.55
Light	–0.14	0.089	0.14
Very light	0.00	0.00	—
Bus traffic			
Very heavy	0.14	0.083	0.11
Heavy	0.073	0.087	0.41
Light	0.009	0.065	0.89
Very light	0.00	0.00	—
Road surface			
Good	–0.04	0.17	0.81
Fair	–0.21	0.18	0.30
Poor	0.00	0.00	—
Temperature (°F)	0.01	0.005	0.06
Relative humidity (%)	0.014	0.003	0.0003

concentrations at all sites at comparable times and circumstances. This makes it difficult to determine whether the air pollution patterns mapped in Figures 4 and 5 represent the true spatial gradient of air pollution or merely temporal or activity-based variability. The incorporation of site characteristics into regression models controlling for temporal autocorrelation theoretically accounted for these factors, but the limited and somewhat imprecise site data imply that some uncertainty remains. Finally, it is difficult to interpret the health implications of significant variability in short-term average concentrations, although this information is relevant for the estimation of personal exposures given activity patterns in the area.

Our community collaboration should also be viewed as a pilot effort with potential areas of expansion and improvement in future analyses. Although our report may not represent a product of the entire Dudley Square community, we were able to strengthen a working relationship between a university and a community-based organization. We also trained local youth in data collection procedures and demonstrated that community members could be incorporated into the data collection phase. Our community-based pilot project ultimately represented an endeavor that met the interests of both researchers and community-based organizations, and it fostered a partnership that can lead to future projects linked to the stated concerns of residents. To influence a greater number of community members in future investigations, we would aim to focus on policy-relevant and solution-based projects. We would also foster greater community linkages through more frequent presentation of the work in community newspapers or at meetings with selected community members.

Despite the limitations in our pilot investigation, our study demonstrated the efficacy of a GIS and LME regression approach in characterizing air pollution patterns in an urban area with constrained monitoring resources. The mobile monitoring protocol coupled with the collection of predictive variables allowed us to visually depict the variability in exposures that could potentially occur in a transportation-intensive area. This allowed for greater ease of interpretation and communication with residents through such media as poster presentations at a conference in Roxbury and presentations at ACE.

A logical extension of this investigation would involve the generation of more systematic GIS information, including measured air pollution, meteorologic conditions, and site characteristics. If a model could be generated with good predictive ability, this could provide useful information for epidemiologic investigations, as personal exposures could be estimated accurately based on activities and place of residence. This would also allow for the extrapolation of these findings to other settings with different source and site characteristics.

Conclusions

We used a mobile monitoring strategy to develop GIS maps of $PM_{2.5}$ and particle-bound PAH concentrations in an urban neighborhood surrounding a large city bus terminal. Concentrations of both pollutants varied significantly both spatially and temporally, with higher levels on weekdays and during morning rush hour, indicating a potential contribution from traffic. Regression models did not find many significant predictors of air pollution concentrations, although both a model using bus route and road characteristics and a model using qualitative traffic information found some evidence of higher concentrations on streets with elevated bus traffic. Further investigation would be needed to conclusively determine the relative importance of spatial and temporal variability and to develop robust predictive models for PAH and $PM_{2.5}$ concentrations.

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