Elemental Carbon and $PM_{2.5}$ Levels in an Urban Community Heavily Impacted by Truck Traffic

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Hunts Point, a 690-acre peninsula in the South Bronx, New York City, is a hub in the tristate (New York, New Jersey, and Connecticut) freight transportation system. This study was carried out in response to community concerns about potential health effects of exposure to diesel exhaust particulate (DEP). We measured particulate matter < 2.5 µm in aerodynamic diameter ($PM_{2.5}$) and elemental carbon (EC) on sidewalks and tested whether spatial variations in concentrations were related to local truck traffic density. Ten-hour integrated air samples for EC and $PM_{2.5}$ were collected for 9 days over a 3-week period in the summer of 1999 at seven geographically distinct intersections. Simultaneous traffic counts were carried out for each sampling event. Traffic was classified into three classes: passenger cars, small trucks, and large trucks (diesel vehicles). Mean diesel vehicle volumes ranged from 9.3 to 276.5 vehicles/hr across sites. Mean EC concentrations by site ranged from 2.6 µg/m^3 at the control site to 7.3 µg/m^3 along a designated truck route. Linear regression of site-specific mean EC concentration on mean large truck counts predicted an increase of 1.69 µg/m^3 EC per 100 large trucks/hr (SE = 0.37; p = 0.01; R^2 = 0.84). Average $PM_{2.5}$ concentrations by site ranged 1.6-fold (19.0–29.9 µg/m^3) and were more weakly associated with local traffic. Variations over time for $PM_{2.5}$ were more pronounced, ranging almost 4-fold (8.9–34.4 µg/m^3). These results show that airborne EC concentrations, an important component of DEP, are elevated in Hunts Point and that the impact varies across the community as a function of large truck traffic.

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In recent years, people living in inner cities have become increasingly concerned about motor vehicle emissions and associated health effects (*1*). These concerns are compounded by high rates of asthma morbidity and mortality among minority children living in underprivileged urban communities (*2,3*). Community organizations have presented evidence that diesel emission sources are often disproportionately concentrated in underprivileged urban neighborhoods. For example, in New York City (NYC), seven of the eight bus depots serving Manhattan are located in Harlem, a traditionally minority community. A recent survey in Boston, Massachusetts, found that there were 15 bus and truck depots concentrated within the low-income community of Roxbury, together housing more than 1,150 diesel vehicles (*4*). The Hunts Point section of the South Bronx, NYC, is home to a low-income population of African Americans and Latin Americans. It is also the principal food-processing terminal for NYC, serviced by 10,000 trucks/day (*5*).

A recent NYC Department of Health survey (*2*) found that

> children from low-income areas of NYC were over four times more likely to be hospitalized for asthma than children from high income areas during 1997.

Among the five boroughs of NYC, the Bronx has ranked highest in both asthma hospitalizations and deaths in recent years. Furthermore, the 1997 asthma hospitalization rate among children 0–14 years of age in the Hunts Point–Mott Haven neighborhood of the South Bronx ranked highest among the Bronx's seven neighborhoods, at 23.2/1,000 population.

The present study was initiated at the request of The Point Community Development Corporation (The Point CDC) and was designed to characterize the relationship between airborne particle concentrations and heavy-duty truck traffic within Hunts Point. Our specific aims were to identify the spatial distribution and travel patterns of truck traffic through the community, to monitor airborne concentrations of particles < 2.5 µm in aerodynamic diameter ($PM_{2.5}$) and elemental carbon (EC) at the sidewalk level adjacent to several intersections that vary in truck density, and to identify potential routing alternatives to minimize residential exposure to emissions.

The human health effects of airborne particulate matter have been examined in numerous recent epidemiologic studies (*6–11*), several of which highlight the special health significance of $PM_{2.5}$, which is a heterogeneous mixture of particles that vary in both composition and sources. In the northeastern United States, a major part of $PM_{2.5}$ is composed of sulfate compounds, which are formed as secondary particles in region-wide air masses as a result of primary sulfur dioxide emissions. Relatively small spatial variations in $PM_{2.5}$ concentrations exist within or between urban areas in this region, reflecting the dominant influence of region-wide sulfate aerosols as major drivers of local $PM_{2.5}$ concentrations (*12–14*). In contrast, $PM_{2.5}$ components associated with local fossil-fuel combustion, such as diesel exhaust particulate (DEP), exhibit greater spatial variations, and these variations have been associated with local traffic sources (*15–18*). In a recent community-driven pilot study, Kinney et al. (*18*) measured concentrations of $PM_{2.5}$ and EC on sidewalks in Harlem, NYC, and tested whether spatial variations in concentrations were related to local diesel traffic density. Mean concentrations of $PM_{2.5}$ exhibited only modest site-to-site variation, reflecting the importance of broader regional sources of $PM_{2.5.}$ In contrast, EC concentrations varied 4-fold across sites (from 1.5 to 6 µg/m^3) and were associated with bus and truck densities on adjacent streets. These pilot results demonstrate that local diesel sources in Harlem create spatial variations in sidewalk concentrations of DEP (*18*).

DEP has diameters in the submicrometer range and is composed largely of EC. DEP has relatively large surface areas onto which a wide range of organic compounds are adsorbed. This organic fraction is a complex mixture containing toxicologically important compounds such as benzene, toluene, ethylbenzene, xylene, and polycyclic aromatic hydrocarbons (PAHs). Common PAHs include phenanthrenes, fluorenes, naphthalenes, fluoranthrenes, and pyrenes, many of which are known mutagens and carcinogens (*19–22*). DEP surfaces also act as a site for the concentration of airborne allergens. Thus, because of their small particle size and

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ability to act as a carrier for toxic organic chemicals and allergens, DEP may play a role in transporting allergens and toxic compounds deep into the respiratory tree (*23,24*).

Recent epidemiologic studies have demonstrated associations between residential proximity to traffic sources and adverse respiratory outcomes, including asthma hospitalizations among children (*25*), increased respiratory symptoms (*26,27*), diminished lung function (*15,16*), and increased prevalence of atopy and allergic disease (*28*). Exposure assessment methodology varies among studies. Few include specific measures of truck and/or bus density or ambient sampling of DEP.

Significantly, studies of health outcomes as a function of truck density or specific DEP exposure have reported stronger associations. Studies in two different German cities using almost identical methodology found that adolescents who reported constant truck traffic outside their homes were two times more likely to also report wheeze than were those who reported no truck traffic (*29,30*). In one recent study, chronic respiratory symptoms and lung function decrements in children were associated with local truck traffic density and with black smoke concentrations in schools, whereas no such associations were observed for car traffic, suggesting a specific effect of diesel exhaust (*16*). The results of these studies support the observations and concerns of inner-city residents with respect to a possible relationship between diesel emission exposure and respiratory disease.

Outdoor exposure to DEP may be of special importance for inner-city residents because sidewalks function both as pathways for pedestrian movement and as venues for play and congregation for children and adults, including the elderly. These uses are especially prevalent in the urban core areas of NYC, where many people live in small apartments without balconies and air conditioning and where public green space is scarce. From a scientific perspective, exposure characterization is a necessary first step in investigating a possible relationship between diesel exhaust exposures and asthma. There are few data on levels and patterns of human exposures to DEP in urban areas. Data relating spatial variations in source density to variations in ambient DEP concentrations in congested urban core neighborhoods are especially lacking.

Materials and Methods

Community background. Hunts Point is a 690-acre peninsula on the southeastern shore of the borough of the Bronx, NYC. It is a hub for freight transportation in the tristate area (New York, New Jersey, and Connecticut). A sprawling food terminal located at the tip of the peninsula handles 80% of the New York metropolitan region's fresh produce. Approximately 10,000 trucks service the food terminal every day. In addition, solid-waste-transfer and construction and demolition stations in the peninsula process 40% of Manhattan's commercial waste.

Hunts Point is also home to 10,000 residents who live and work in the area (including 3,000 children). According to the 1990 U.S. Census (*31*), 73% of residents are Hispanic Americans, and 25% are African Americans, with 2% belonging to other ethnicities. Half of community residents live at or below the poverty line. One out of three Hunts Point children suffers from asthma, and the risk of hospitalization for asthma among children is 12 times the national average (*2*). Figure 1 shows the location of the market and designated legal truck routes through the community.

Selection of monitoring sites. We identified seven potential monitoring sites on the basis of known traffic patterns and extensive consultation with The Point CDC and area residents. The stations were chosen to meet two criteria: first, the need to measure a range of traffic densities and associated emissions, and second, the need to monitor air pollution at sites of importance to the community. Community members were particularly interested in assessing exposures near popular gathering spaces, in high-density residential areas, and near schools and playgrounds. Pilot traffic counts were made at the potential sites to ensure that the selected sites would indeed provide a spectrum of traffic densities. Figure 2 shows the locations at which traffic and air monitoring were conducted.

Site 1 was located at the intersection of Tiffany Street and Spofford Avenue, a busy intersection marking the boundary between residential and commercial areas. Tiffany Street is a designated truck route that links the Bruckner Boulevard expressway on the northwest border of Hunts Point with the food-processing terminal and over 30 waste-transfer and construction and demolition facilities located in the commercial area. An apartment building also stands at this intersection. Site 2 was located at the intersection of Longfellow and Lafayette Avenues. Buildings surrounding this intersection include a school, a number of automotive used parts depots, and apartment buildings. Neither Longfellow Avenue nor Lafayette Avenue is a designated truck route, so this site was expected to have little truck traffic. Site 3 was located at the intersection of Spofford Avenue and Coster Street, in the heart of the residential area. A school and a daycare center border on this intersection. After a fatal accident in which a young girl was killed by a truck, residents have succeeded in having traffic-calming devices and medians constructed around this intersection. Site 4 was located at the intersection of Tiffany Street and Randall Avenue, both of which serve as truck routes to the warehouses, demolition facilities, sewage-processing facilities, and food terminal. Thus, this intersection was highly congested. Site 5 was located at Hunts Point and Randall Avenues; here again, both streets were designated truck routes. This intersection, in the commercial area, was unusually spacious and open. Site 6, located in a no-truck-traffic zone in the sheltered garden of a home on a residential street, served as a control site for air monitoring.

Sampling design. Air monitoring (all sites) and traffic counting (sites 1–5) were conducted by teams of two student interns and/or community residents who sat on sidewalks adjacent to the intersections. These 14–18-year-old interns were participants in a

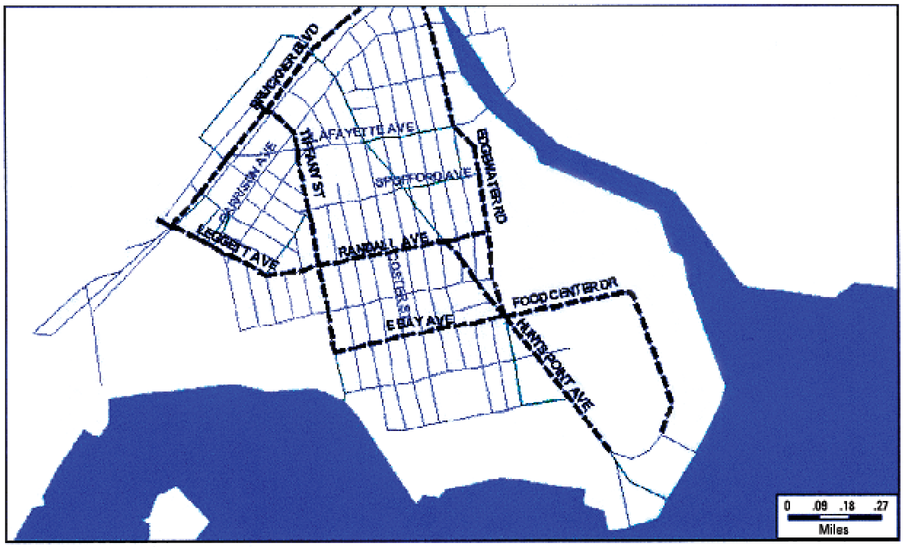

Figure 1. Major truck routes in Hunts Point.

environmental leadership development program run jointly by Hunter College and community organizations in Hunts Point, Nos Quedamos, and Sunset Point, also in Bronx, NYC. Staff from Columbia University trained the students and community partners in the operation, calibration, and proper placement of air sampling equipment. A scientific staff member from Columbia University rotated from site to site throughout all sampling periods and was responsible for oversight of the sampling operations at each site.

Air sampling and traffic counting were carried out on Monday, Tuesday, and Wednesday for 3 consecutive weeks beginning 25 July 1999 and ending 12 August 1999. Because of staff and equipment constraints, all sites could not be monitored on all days. At sites 1–3, measurements were conducted on Mondays and Wednesdays. Sites 4 and 5 were monitored on Tuesdays. To provide an estimate of temporal changes in background concentrations, air monitoring at site 6, the control site, was carried out on all days (i.e., Monday through Wednesday each week). No traffic counts were made at site 6 because the air sampling equipment was placed within an enclosed garden. Measurements at each site covered a 10–12-hr period starting at 600 hr each day. The sampling schedule reflected the best compromise between the need for maximum duration of counting and sampling periods, the need to capture traffic volumes during morning peaks (600–800 hr) and evening peaks (1600–1800 hr), and availability of field staff. We chose July and August because of the availability of summer interns and to avoid the heating season when coal and oil furnaces emit EC. The study was limited to weekdays to focus on typical commercial traffic volumes.

Particle concentration measurements. Integrated 10–12-hr $PM_{2.5}$ samples were collected at each site using 4-L/min battery-operated personal sampling pumps (Gil-Air 5; Gillian Instrument Corp., W. Caldwell, NJ) attached by flexible tubing to polyethylene filter sampling cartridges (University Research Glassware, Carrboro, NC). The cartridge had an inlet nozzle and a greased impactor plate that eliminated particles > 2.5 µm in aerodynamic diameter from the air stream before collection on the filter. The cartridge contained a preweighed Teflon filter for gravimetric $PM_{2.5}$ analysis and reflectance analysis. For a subset of sampling events, colocated particle samples were collected onto quartz fiber filters. These were subsequently analyzed for EC. The quartz filter samples were collected at 3 L/min with no impactor because virtually all EC is contained in particles smaller than 1 µm.

Air sampling at sites 1–5 occurred on sidewalks adjacent to the intersection. Pumps were placed on chairs approximately 1m from the curbside, and the sample cartridges were taped to the chair backs.

Flow rates were checked by scientific staff with precalibrated rotameters before, during, and after each sampling event. After sampling, cartridges were separated from the tubing, capped, and then placed in resealable bags for hand transport to a laboratory at Hunter College. At the laboratory, scientific staff disassembled the cartridges and removed the filters under a positive-pressure, particle-free hood. Teflon filters were placed in individual sterile petri dishes and shipped to external laboratories for gravimetric $PM_{2.5}$ analysis. Cartridges with quartz filters were shipped intact to external laboratories for EC analysis.

Gravimetric $PM_{2.5,}$ EC, and reflectance analysis procedures. Gravimetric $PM_{2.5}$ analysis was performed in the laboratories of P. Koutrakis at the Harvard School of Public Health (Boston, MA). Quartz filters were analyzed for EC by Sunset Laboratories, Inc. (Forest Grove, OR). The methods have been described in detail previously (*18*).

Reflectance analysis was performed in the laboratories of S. Chillrud (Lamont Doherty Earth Observatory, Columbia University) as described previously (*18*). The blackness of the filter deposit was measured using an EEL (Evans Electroselenium Ltd.) smoke stain reflectometer (model 43D; Diffusion Systems Ltd., London, UK). An absorption coefficient was determined for each filter.

Traffic counting. Vehicle counts per unit time were determined visually at each intersection for each day of sampling. Two community interns were stationed at each intersection, with each intern counting traffic on a different street so that all traffic at a given intersection was counted. Data entry sheets for recording traffic counts were provided by traffic engineers at City University of New York (CUNY). The data entry sheets allowed traffic counters to record type, volume, and direction of traffic flow (including right and left turns). One data entry sheet was used to count traffic in both directions on one street for a 15-min period. On each data entry sheet, observers recorded the station reference, time of day, interval of observation, weather, traffic volumes exiting intersections in different directions, and the traffic control devices (e.g., traffic lights, stop signs). Traffic was counted in three classes: passenger cars, including vans and sport utility vehicles (P); pickup trucks and double-axle trucks (small trucks, T1); and trucks with two axles that have two tires on the front axle and four tires on the rear axle, or trucks with more than two axles (large trucks, T2).

U.S. Department of Commerce data (*32*) on characteristics of vehicles registered in the tristate area indicates that < 4.0% of trucks in our T1 category have diesel engines. In contrast, 95% of trucks with more than three axles have diesel engines. Approximately 45% of trucks with two axles (front axle has two tires, rear has four tires) have diesel engines. Both types of vehicles were classified as T2 in our study; thus, this category is likely to be relatively sensitive for DEP exposure (*32*).

A traffic engineer from CUNY trained interns and staff from Columbia University and The Point CDC in traffic counting techniques. During two training sessions at a busy intersection in Hunts Point, observers were instructed in the use of data entry sheets, the proper traffic lanes and directions to be counted, and delineation between the three classes of traffic under study. Traffic data were entered onto a spreadsheet and expressed in counts per hour for each vehicle category, for all traffic (P + T1 + T2) and for all trucks (T1 + T2).

Figure 2. Sampling sites for the Hunts Point air pollution study.

Statistical analysis. Simple descriptive statistics were tabulated to display spatial and temporal variations in traffic density and EC and $PM_{2.5}$ concentrations across the six monitoring sites. Also, correlations among the counts of passenger cars, small truck, and large trucks were examined. Likewise, correlations were calculated between traffic counts and both EC and $PM_{2.5}$ concentrations.

Analytical EC measurements on quartz fiber filters were available for a subset of 13 of 33 sampling events. However, the Teflon filters used to measure $PM_{2.5}$ concentrations were subsequently analyzed by reflectance to determine the adsorption coefficient of the particle deposit, a surrogate for EC content of the sample. To estimate EC concentrations for sampling events lacking quartz filter analyses, we used a regression equation of EC (analyzed on quartz filters) on absorption coefficient (analyzed on colocated Teflon filters) developed within the data subset. The scatter plot of EC versus absorption coefficient for the 12 colocated samples indicated a close correspondence between the two measures, with a correlation of 0.90. A linear regression through the origin was fit, yielding a slope of 0.5236 $\mu g/m^3$ EC per unit absorption coefficient. Using this slope, estimated EC concentrations (in micrograms per cubic meter) were calculated as a linear function of absorbance for all sampling events that lacked an EC determination.

To assess the relative magnitude of spatial and temporal variations in large truck counts, EC, and $PM_{2.5}$ concentrations, data were analyzed by two-way analysis of variance (ANOVA) with site and date as the two main random effects. To quantify the relationship between large truck counts and airborne particle concentrations, site-mean EC and $PM_{2.5}$ concentrations were regressed on site-mean truck counts.

As noted above, although the control site (site 6) was sampled on all 9 study days, logistical constraints required that sampling at the remaining five sites be staggered, with sites 1–3 sampled on Mondays and Wednesdays, and sites 4 and 5 sampled on Tuesdays over the 3-week study period. This somewhat unbalanced design could have resulted in confounding between temporal and spatial variations in air quality if, by chance, air quality differed on average between the two sampling frames. To address this concern, we compared the Monday and Wednesday data with the Tuesday data for EC and $PM_{2.5}$ at the control site, which was monitored on all days. This comparison was made using the unpaired *t*-test.

Results

Average hourly counts of large trucks, small trucks, and passenger cars for each site and day are summarized in Table 1. Each value represents the average hourly count observed over the course of a 10–12-hr counting period on each day. Table 1 also presents the means and standard errors of traffic counts by site. These data show that average vehicle counts varied markedly from site to site and that these intersite differences were especially great for large trucks. Site-specific mean passenger car counts ranged just 2.2-fold across sites, from 155.4 to 348.3 vehicles/hr. Small truck counts showed a slightly higher range across sites of 4.9-fold, from 33.3 to 161.7 vehicles/hr. However, site-specific means for large trucks ranged from 9.3 to 276.5 vehicles/hr, almost a 30-fold range. In a two-way random-effects ANOVA, the site-to-site differences were highly significant for all three vehicle types, whereas the day-to-day differences were consistently nonsignificant.

Passenger car counts exceeded small and large truck counts at all sites; however, the ratio of passenger cars to trucks varied by site. At site 3, this ratio was 19:1, but at site 4, at the intersection of two truck routes, the ratio was 1.25:1. All traffic classes were correlated with one another, with large trucks and small trucks (r = 0.90) being most correlated and

Table 1. Average hourly counts of passenger cars, small trucks, and large trucks at five sites in Hunts Point.

	Week 1			Week 2			Week 3				
Vehicle type/site	Monday 7/26/99	Tuesday 7/27/99	Wednesday 7/28/99	Monday 8/2/99	Tuesday 8/3/99	Wednesday 8/4/99	Monday 8/9/99	Tuesday 8/10/99	Wednesday 8/11/99	Mean	SE
Passenger cars/hr											
1	295.2		252.5	227.7		339.5	277.6		375.5	294.7	22.4
2	237.8		178.2	96.4		183.4	65.7		171.1	155.4	25.7
3	171.6		169.3	188.2		170.9	194.7		172.7	177.9	4.4
4		331.0			319.4			385.3		345.2	20.3
5		314.8			381.7					348.3	33.4
Small trucks/hr											
1	91.4		93.8	107.2		97.8	85.5		98.0	95.6	3.0
2	70.2		57.5	46.5		61.0	12.8		73.6	53.6	9.1
3	52.1		37.9	25.9		29.2	28.4		26.2	33.3	4.2
4		171.4			169.7			144.2		161.7	8.8
5		134.6			177.4					156.0	21.4
Large trucks/hr											
1	109.9		130.6	119.1		124.2	134.5		126.6	124.2	3.6
2	17.4		14.3	11.4		13.8	7.2		13.1	12.9	1.4
3	7.8		12.1	10.1		9.6	9.1		7.1	9.3	0.7
4		231.4			304.3			293.7		276.5	22.7
5		149.8			155.3					152.5	2.7

Table 2. Airborne elemental carbon concentrations ($\mu g/m^3$) at six sites in Hunts Point.

	Week 1			Week 2			Week 3				
Site	Monday 7/26/99	Tuesday 7/27/99	Wednesday 7/28/99	Monday 8/2/99	Tuesday 8/3/99	Wednesday 8/4/99	Monday 8/9/99	Tuesday 8/10/99	Wednesday 8/11/99	Mean	SE
1	6.20		5.44	5.13		6.00	4.71		7.70	5.86	0.43
2	2.94		3.25	2.54		1.99	1.17		3.86	2.62	0.39
3	2.70		3.29			2.29	1.43		3.30	2.60	0.35
4		7.24			6.34			8.45		7.34	0.61
5		4.03			3.56					3.80	0.24
6	1.90	2.46	2.82	2.06	1.94	2.96	0.72	4.75	3.56	2.57	0.38
Mean	3.44	4.58	3.70	3.24	3.95	3.31	2.01	6.60	4.60		
SE	0.95	1.41	0.59	0.96	1.29	0.92	0.91	1.85	1.04		

passenger cars and large trucks being least correlated ($r = 0.82$).

Mean EC concentrations by site ranged almost 3-fold, from approximately 2.6 μg/m^3 at the control site (site 6) and the two residential street sites (sites 2 and 3) to 3.8 (site 5), 5.9 (site 1), and 7.3 μg/m^3 (site 4) along the truck routes (Table 2). Day-to-day variations in EC concentrations were less pronounced than were site-to-site variations. In a two-way random-effects ANOVA, intersite differences accounted for 80% of the total variance in EC concentrations, whereas interday differences accounted for just 16%. This reflects the relative importance of local motor vehicle emissions, as opposed to long-range transport or alternating weather fronts, as the key driver of ambient EC concentrations in NYC.

To further investigate the influence of local vehicle traffic on intersite variations in EC concentrations, we correlated site-specific mean EC concentrations with site-specific mean vehicle counts per hour. The largest correlation ($r = 0.92$) was observed between EC and large truck counts; for passenger cars and small trucks, the correlations with EC were 0.72 and 0.75, respectively. Figure 3 displays the scatter plot and linear regression of site-mean EC versus large truck counts per hour, indicating a strong positive relationship. The linear regression predicted an increase of 1.69 μg/m^3 EC/100 large trucks/hour (SE = 0.37; $p = 0.01$), with an R^2 of 0.84.

Average PM$_{2.5}$ concentrations by site ranged 1.6-fold, from 19.0 μg/m^3 at the control site to 29.9 μg/m^3 at site 1 (Table 3). Variations over time were more pronounced, ranging almost 4-fold, from 8.9 to 34.4 μg/m^3. A two-way ANOVA showed that interday differences accounted for 55% of the total variance in PM$_{2.5}$ whereas intersite differences accounted for 24% of total variance. This reflects the relative importance of long-range transport and alternating weather fronts, as opposed to local emissions, as drivers of ambient PM$_{2.5}$ concentrations in NYC. Correlations between site-specific mean PM$_{2.5}$ concentrations and mean vehicle counts per hour were somewhat lower than was observed for EC: 0.62, 0.58, and 0.72 for passenger cars, small trucks, and large trucks, respectively. Figure 4 displays the scatter plot and regression of site-mean PM$_{2.5}$ versus large truck counts per hour. A weak positive relationship was observed, with PM$_{2.5}$ concentrations increasing by 3.26 μg/m^3/100 large trucks/hr (SE = 1.56; $p = 0.11$), with an R^2 of 0.52.

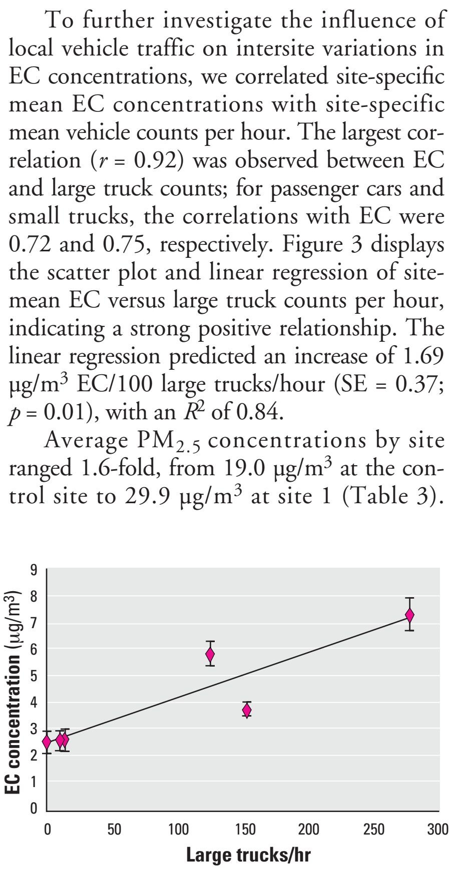

Figure 3. Plot of site-specific mean EC (± SE) versus mean large truck counts, with linear regression line. EC = 0.0169 × trucks + 2.51 ($R^2 = 0.84$).

The ratios of EC to PM$_{2.5}$ for individual samples ranged from 0.09 to 0.38, with a mean of 0.17. Average EC/PM$_{2.5}$ ratios at the control and nontruck route sites (sites 2, 3, and 6) were lower, ranging from 0.13 to 0.16. In contrast, average EC/PM$_{2.5}$ ratios were higher at the truck route sites (sites 1, 4, and 5), ranging from 0.20 to 0.28.

Using the regression slopes noted above for both EC and PM$_{2.5}$ in relation to large truck counts, we estimated the fraction of total truck-related PM$_{2.5}$ that was represented by EC in the present study. The ratio of the regression slopes (expressed in units of micrograms per cubic meter per 100 trucks), 1.69/3.26 or 0.52, indicates that EC represented 52% of the impact that large trucks had on PM$_{2.5}$ concentrations. Conversely, we can estimate the total PM$_{2.5}$ impact of large trucks by multiplying the observed EC concentrations by the ratio of the PM$_{2.5}$ slope on trucks to the EC slope on trucks (i.e., 3.26/1.69, or 1.93). Applying this factor to the observed site-specific EC concentrations yields estimates of truck-related PM$_{2.5}$ concentrations ranging from 5.0 μg/m^3 at site 6 to 14.2 μg/m^3 at site 4. These estimates of truck-related PM$_{2.5}$ represent 26% and 50%, respectively, of the observed mean PM$_{2.5}$ concentrations at these two sites.

Sites 1–3 were sampled on Mondays and Wednesdays, whereas sites 3 and 4 were sampled only on Tuesdays; site 6 (control) was sampled all days. To address whether this somewhat unbalanced sampling design might have resulted in confounding of intersite differences by day-of-week differences, we tested whether mean concentrations of EC or PM$_{2.5}$ at the control site were different on Mondays and Wednesdays compared with Tuesdays using a simple unpaired *t*-test. There was no evidence for differences across the two sampling frames for either EC ($p = 0.41$) or PM$_{2.5}$ ($p = 0.49$), alleviating concerns about potential confounding by day of week.

Discussion

In this study we demonstrated that local variations in traffic density were strongly associated with spatial variations in EC concentrations measured on sidewalks in the Hunts Point neighborhood of the South Bronx. Because diesel trucks were the principal source of traffic-related EC emissions in this community, this finding highlights the important role played by truck traffic as a determinant of spatial variations in exposures to the carbonaceous components of fine particles in this community. Sidewalk levels of total PM$_{2.5}$ were more weakly associated with large truck traffic, being more strongly influenced by long-range transport of well-mixed sulfate and nitrate aerosols and only partially influenced by local traffic emissions. The mean EC concentration observed in this study, 3.77 μg/m^3, represented 17% of the mean PM$_{2.5}$ concentration, 22.3 μg/m^3.

EC represents only a portion of the particle emissions from diesel vehicles; other components of DEP include a variety of organic compounds and metals. In addition, particles can be resuspended from roadways by the movement of tires. Although not directly measured in this study, the total contribution of large truck traffic to PM$_{2.5}$ concentrations can be estimated. One method for deriving this estimate is based on the ratio of the regression slope of EC on large trucks to the slope of PM$_{2.5}$ on large trucks, or 0.52 in the present study. This implies that EC represents 52% of the total PM$_{2.5}$ generated by large

Table 3. Airborne PM$_{2.5}$ concentrations (μg/m^3) at six sites in Hunts Point.

	Week 1			Week 2			Week 3				
Site	Monday 7/26/99	Tuesday 7/27/99	Wednesday 7/28/99	Monday 8/2/99	Tuesday 8/3/99	Wednesday 8/4/99	Monday 8/9/99	Tuesday 8/10/99	Wednesday 8/11/99	Mean	SE
1	26.5		24.4	22.5		43.0	14.7		48.1	29.9	5.25
2	24.8		22.9	19.8			9.5		28.6	21.1	3.22
3			13.6	18.7		17.3	6.9		31.9	18.2	3.39
4		36.3			26.3			22.0		28.2	4.25
5		27.0			14.4					20.7	6.28
6	17.8	27.5	20.1	17.6	14.1	17.0	4.5	23.3	29.2	19.0	2.46
Mean	22.5	30.3	20.2	19.6	18.3	25.8	8.9	22.7	34.4		
SE	1.95	3.03	2.39	1.22	4.00	7.46	2.20	0.69	4.61		

trucks. Furthermore, if we assume that diesel vehicles were the dominant source of EC in this study (which is reasonable given the lack of oil or coal combustion for space heating in the summer months), it is possible to estimate a total $PM_{2.5}$ contribution from diesel traffic emissions of 7.25 μg/m^3 (i.e., 1/0.52 × 3.77 μg/m^3). This represents 32.5% of the mean $PM_{2.5}$ concentration measured in this study (ranging from 26% to 50% for individual sites). In a previous study in Los Angeles, California, Cass and Gray estimated that EC represented 59.5% of the mass of DEP observed in the Los Angeles atmosphere, a value similar to our estimate of 52% (*33,34*). Applying the Cass and Gray estimate to the mean EC concentration observed in this study (1/0.595 × 3.77 μg/m^3) yields an estimated total DEP concentration of 6.34 μg/m^3 (*33,34*).

Correlations among traffic classes (passenger vehicles, small trucks, and large trucks) were high in this study, ranging from 0.82 to 0.90, making it difficult to separate the influences of different vehicle classes on air quality. However, a stronger correlation was seen between large trucks and EC than between small trucks and EC ($r = 0.92$ vs. $r = 0.75$).

In this study, trucks with two axles and six wheels (two in front, four behind) and vehicles with three axles or more were counted together as a single traffic class (T2). In pilot counts with student interns, we found that this classification scheme achieved the greatest precision in measurement. However, grouping vehicles in this way diminished our ability to distinguish the specific pollutant contribution of diesel trucks. In the local area, approximately 45% of two-axle, six-wheel trucks have diesel engines. The proportion with diesel engines is closer to 65% for trucks of this kind that are used in wholesale businesses, which are common in Hunts Point. Thus, in our study area, the proportion of trucks in this class with diesel engines is likely to have been between 45% and 65%. In contrast, > 90% of trucks with three axles (100% for wholesale freight transport) have diesel engines (*32*). Thus, our measurement of the relationship between diesel trucks and sidewalk-level DEP exposures would have been more accurate if we had counted three-axle vehicles separately. Indeed, the relationship between diesel trucks and sidewalk-level EC and $PM_{2.5}$ is likely to be stronger than reported in this study.

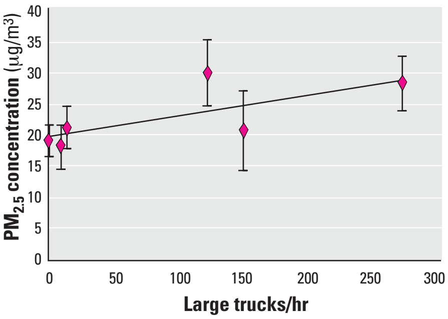

Figure 4. Plot of site-specific mean $PM_{2.5}$ (± SE) versus mean large truck counts, with linear regression line. $PM_{2.5} = 0.0326 \times \text{trucks} + 19.73$ ($R^2 = 0.52$).

In our study, local variations in traffic density were measured using simple visual traffic counts at the same intersection where air monitoring occurred. A more complete analysis of local traffic impacts on air quality would account for traffic not only on the adjacent street but also on other nearby streets, especially those upwind of the monitoring site. In the Hunts Point area, the contribution of trucks idling at warehouses and construction and demolition sites may be particularly important. Modeling the cumulative impact of sources throughout the community would have required sophisticated dispersion models, which were beyond the scope of this small study.

The significance of the DEP concentrations observed in this study for asthmatic persons living in the Hunts Point community is not known. In a study of lung function and air pollution from truck traffic conducted in the Netherlands, Brunekreef et al. (*16*) measured black smoke concentrations ranging from 5.15 μg/m^3 to 20.78 μg/m^3 in schools located near motorways. Black smoke was determined using reflectance analysis of PM_{10} samples, in contrast to $PM_{2.5}$ samples used here. Lung function was associated with the concentration of black smoke, and the association was stronger in girls than in boys (*16*). Recent experimental studies have demonstrated that a one-time, intranasal dose of 0.30 mg DEP in saline can synergize with coadministered allergen to enhance allergen-specific IgE production, histamine release, and proinflammatory cytokine levels in the upper respiratory tract (*35–37*).

We did not make direct measurements of respiratory health indicators among community residents. As a step toward understanding the health significance of DEP exposures measured in Hunts Point, we have estimated both a 24-hr and a 2-week dose for a child living in this community. In Hunts Point, scarcity of air conditioning may increase indoor concentrations of ambient pollutants during the summer. The lack of air conditioning may also drive residents outdoors, thereby increasing exposure to ambient pollutants. The small size of apartments, high population density, and lack of sheltered green spaces may also increase reliance on streets as places for children to play and neighbors to meet and talk. Furthermore, in a recent study, Chillrud et al. (*38*) showed a 1-to-1 relationship between indoor and outdoor black carbon measurements at the homes of 38 high school students in NYC. For these reasons we assume that outdoor and indoor DEP concentrations in Hunts Point are roughly equivalent.

An 8-year-old child who spends 12 hr/day resting, 10 hr engaged in light activity, and 2 hr engaged in heavy activity would have a 24-hr cumulative dose of 28.4 μg DEP. This calculation is based on our measured average DEP concentration of 6.34 μg/m^3, a deposition fraction in the tracheobronchial tree of 0.4 for $PM_{2.5}$, and exertion-dependent minute ventilation for an 8-year-old child with height and weight of 127 cm and 27 kg, respectively (*39*). This amounts to a cumulative dose of 396 μg DEP over 2 weeks. Based on our data, a maximum exposure for a child from the community over a 24-hr period would be 67.8 μg. A 2-week dose at maximum exposure levels would be 949 μg. Significantly, the average 2-week dose of 396 μg exceeds the dose used by Diaz-Sanchez et al. (*35*) to elicit enhanced IgE production and cytokine release. Minute ventilation can increase dramatically with exercise; thus, active children are likely to receive much higher doses.

To estimate individual exposure and internal dose more precisely, studies of ambient air pollutants must be combined with indoor air

Table 4. Elemental carbon concentrations in ambient air.

Location and year	Concentration (μg/m^3)	Reference
Annual average outdoor concentrations across 10 sites in the Los Angeles, California, Basin 1982	3–5	(*33*)
Maximum daily concentration		
Los Angeles, 1987	5.4	(*40*)
Welby, Colorado	1.7	(*41*)
Brighton, Colorado	1.2	(*41*)
Harlem, NYC, daily averages (4 sites, sidewalk level)	1.5–6.0	(*18*)
Dusseldorf urban street level, 1991–1992		
Annual workday average	16	(*42*)
Annual weekend average	10	(*42*)
Duisberg, residential area		
Annual average, 1991–1992	3	(*42*)
Hunts Point, 1999		
Average over six sites	3.8	This study
Range of site averages	2.6–7.3	This study

measurements and analysis of activity patterns of residents who differ by age and socioeconomic status. Furthermore, experimental and epidemiologic studies that differentiate between the respiratory effects of chronic and acute exposures to DEP will contribute to our understanding of how DEP exposure may affect respiratory health in this community.

EC levels observed in the present study were somewhat higher than those reported in previous studies. In a recent study in Harlem, daytime EC concentrations measured on sidewalks averaged between 1.5 and 6.2 µg/m^3 across four sites that varied markedly in diesel vehicle traffic (*18*). Average concentrations of EC at the sidewalk level in the Hunts Point area ranged from 2.57 to 7.34 µg/m^3. Table 4 presents results from recent studies of ambient EC levels measured in North America and Europe. Recent source apportionment studies by the U.S. Environmental Protection Agency (EPA) reported that long-term average DEP concentrations, of which EC represents the major part, range between 1.2 µg/m^3 and 3.6 µg/m^3 in urban/suburban areas (*40*). Concentrations in rural or remote areas are generally lower than 1.0 µg/m^3 (*41*). Thus, DEP levels in Hunts Point were relatively high, perhaps because of the high concentration of both local diesel traffic and the upwind proximity of two major highways with heavy truck traffic.

Studies in Berlin and NYC indicate a high degree of correlation between EC concentrations measured analytically on quartz fiber filters and absorption coefficient measurements of $PM_{2.5}$ collected on Teflon filters (*42*). In this study, we report a similarly high correlation ($r = 0.90$). Our results provide further validation of the use of absorption coefficient as an economical surrogate for measurement of fine-particle EC concentrations.

This study provides new data on the relationship between DEP, $PM_{2.5}$, and local traffic density. We have also demonstrated the feasibility of community–university partnerships working to address environmental health problems in marginalized communities. The study design represented a true synthesis of community and university objectives, reflected in the choice of monitoring sites, designation of traffic categories, methods of measurement, and outcomes measured. Although we have not reported the results here, an important additional community objective was to monitor illegal use of nondesignated truck routes, for which some evidence was obtained. The study also provided young people from the community with exposure to scientific methods applied to environmental health problems. This model of community-driven research is particularly appropriate in underprivileged communities that have traditionally been subject to studies conducted by and for the benefit of outside parties.

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