Near-Roadway Health Effects

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Outline of presentation

- Rationale for focusing on near-roadway health effects
  - Epidemiological evidence
  - Exposure assessment studies
- Implications for monitoring and regulation
  - Case study: NAAQS for NOx
- Conclusions and future directions

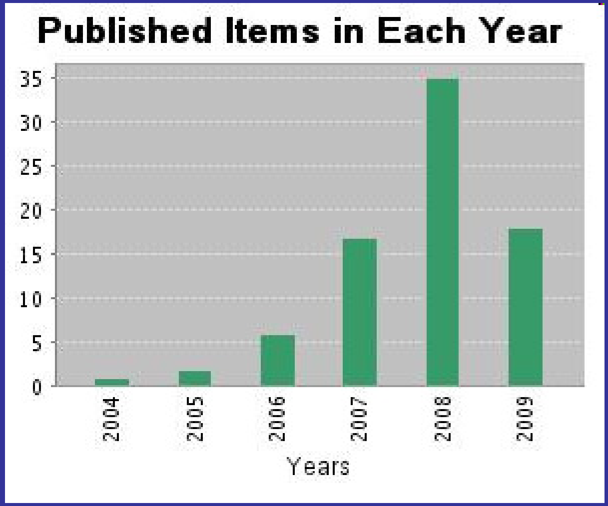
Key observation

- "Near-roadway health effects" is a complex and insufficiently characterized topic, since it includes multiple air pollutants, noise, socioeconomic indicators, and other risk factors. It is also not addressed well by the current EPA monitoring regimen.
- This raises significant challenges for regulation, as well as the need for better science to help determine the attributes of near-roadway exposures causally associated with health outcomes

State of health literature

- Fairly large literature linking respiratory and cardiovascular effects with GIS-based measures of traffic
- Smaller (but rapidly growing) literature where concentrations of specific traffic-related pollutants have been quantified
  - Often NO_2, sometimes EC, sometimes $PM_{2.5}$ with fine-scale spatial modeling

Search for “land use regression”



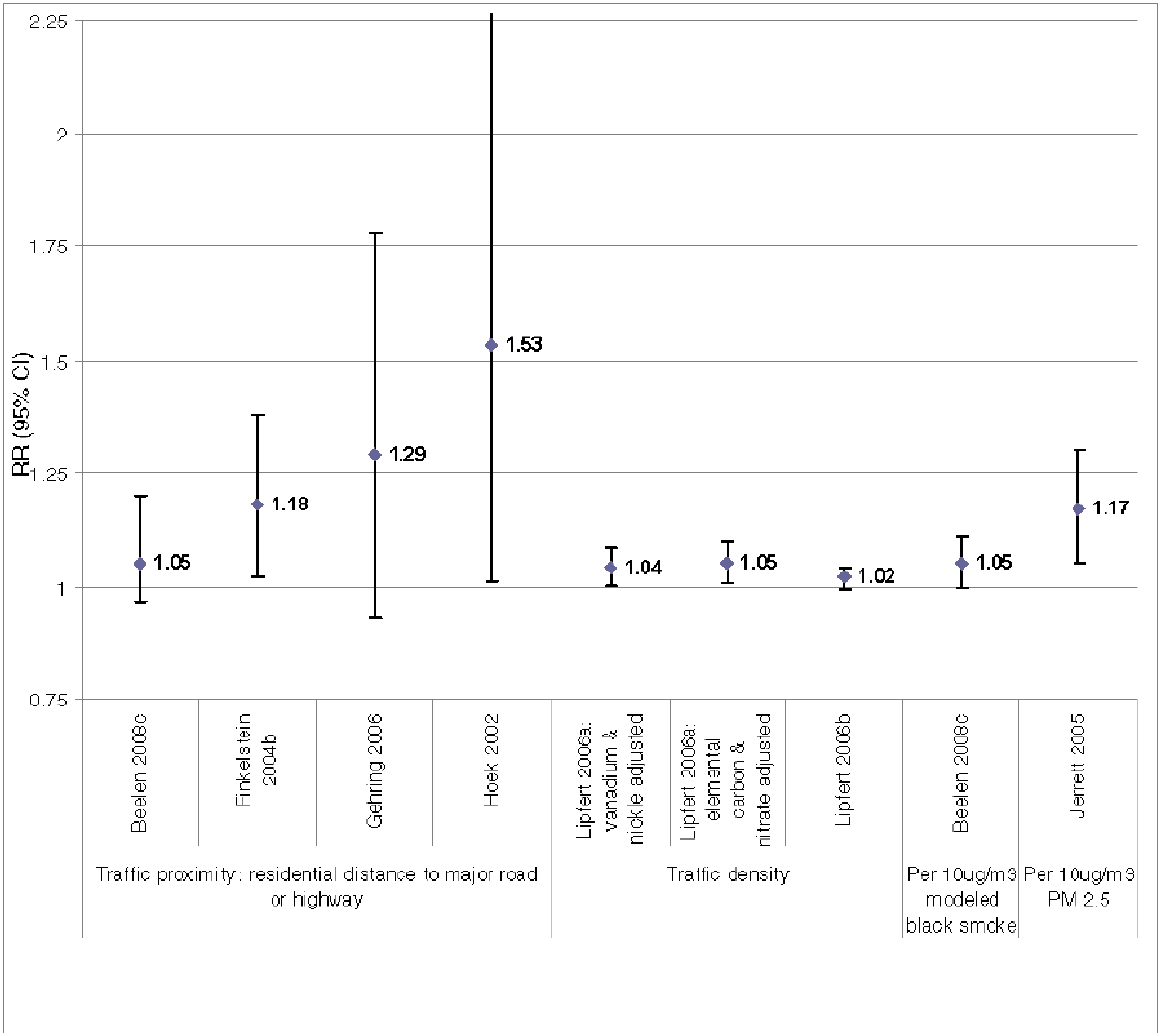


Figure 4.1. Studies of long-term exposure to traffic pollution and all-cause mortality (see Table 4.3).

HEI, 2009

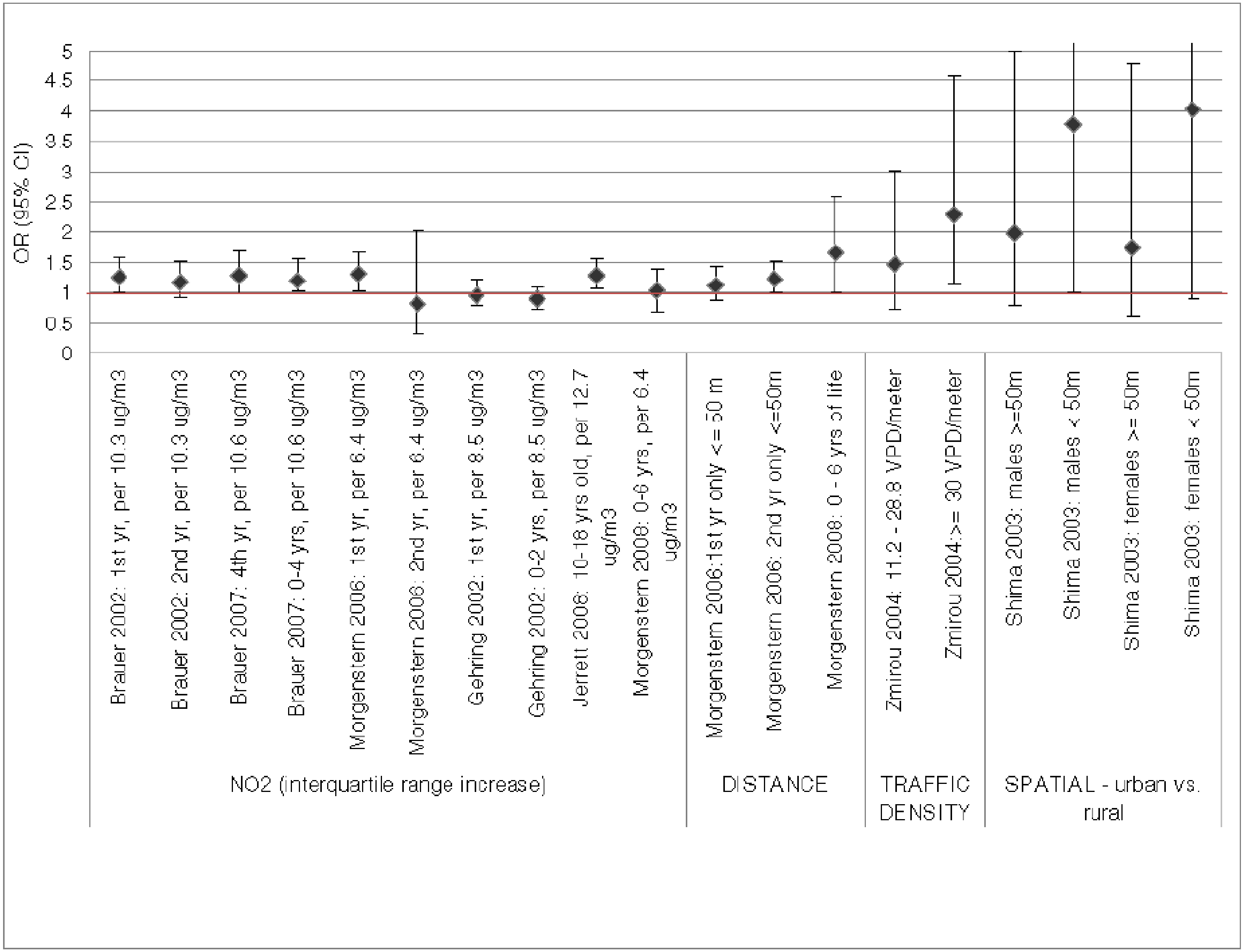


Figure 4.5 Studies of exposure to traffic pollution and doctor-diagnosed asthma incidence in children (see also Table 4.8)

HEI, 2009

Conclusions of 2009 HEI report

- Sufficient evidence
  - Mortality
  - Exacerbation of asthma in children
- Suggestive but not sufficient evidence
  - Cardiovascular morbidity
  - New-onset asthma
  - Exacerbation of asthma in adults
  - Pulmonary function
- Insufficient evidence
  - Health care utilization and symptoms for asthma
  - COPD
  - Allergies
  - Cancer
  - Neurotoxicity

Strong caveats

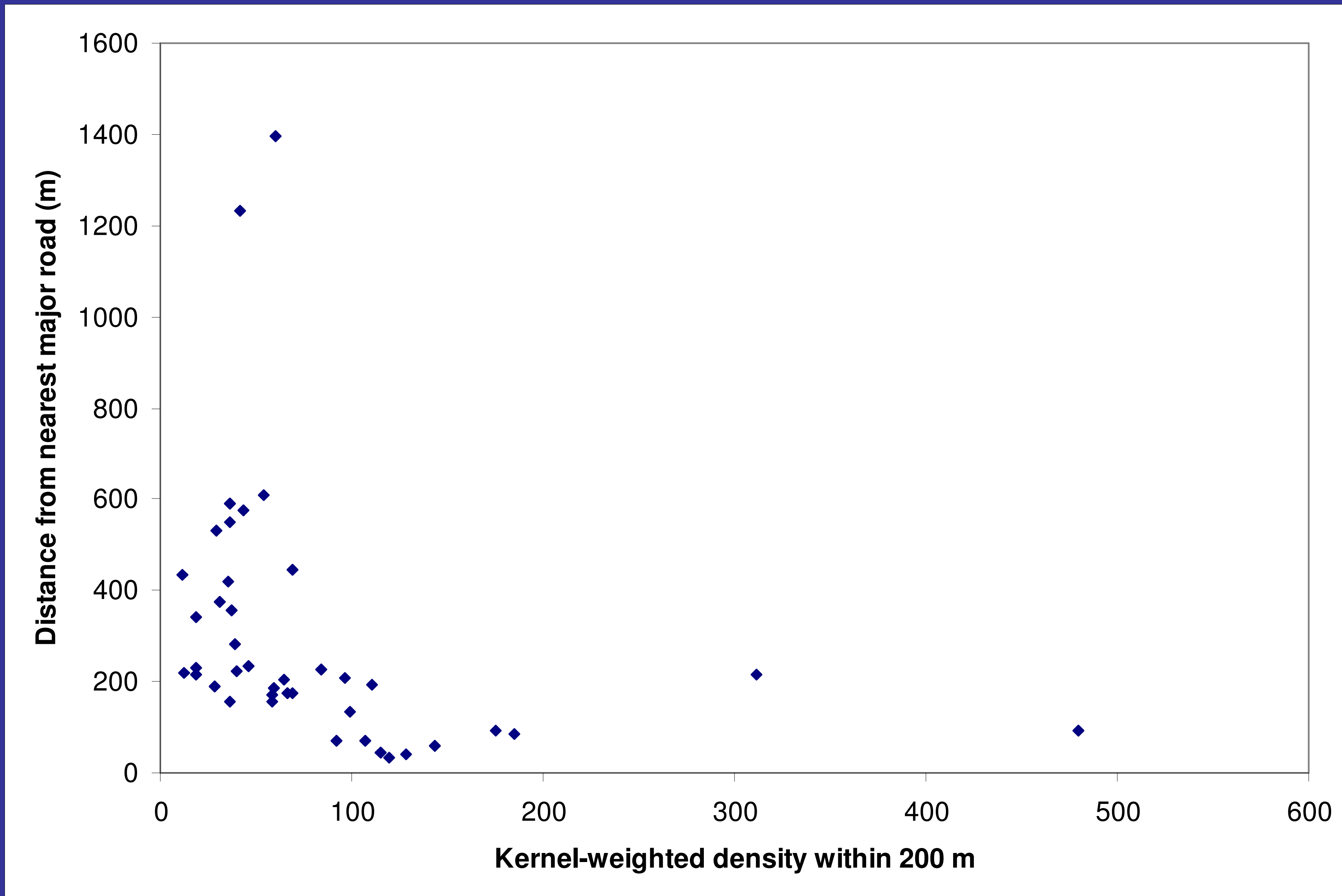
- HEI report used fairly strict criteria for causality
- Focus was on near-roadway literature, not all pollutants/exposures related to motor vehicles
- Lack of proof is not proof of lack
  - "Insufficient evidence" often meant a relatively small number of publications, not a biologically implausible association
  - Coherence argument would indicate likelihood of a continuum of responses

Returning to exposure

- Candidate approaches for near-roadway exposure characterization
  - Residential proximity to roadways
  - Land use regression modeling (outdoor concentrations)
  - Expanded land use regression modeling (indoor concentrations/personal exposures)
  - Atmospheric dispersion modeling

Is “proximity to traffic” one-size fits all?

Unweighted density within 50 m, 100 m, 200 m, 300 m, 500 m buffer
Kernel-weighted density within 50 m, 100 m, 200 m, 300 m, 500 m buffer
Total roadway length within 50 m, 100 m, 200 m, 300 m, 500 m buffer
Total average daily traffic on nearest major road
Total average daily truck traffic on nearest major road
Total average daily traffic*road length within 200 m buffer
Distance to nearest major road, urban road, highway
Distance to nearest designated truck route



Values from Clougherty et al., 2008

Outdoor LUR modeling

Table 1
Association between ambient nitrogen dioxide (on a logarithmic scale) and land-use variables: multiple linear regression model

Variable	Unit	All valid results included ($n = 67$, $R^2 = 0.545$)		Locations <100 m from highway excluded ($n = 61$, $R^2 = 0.585$)		Locations <200 m from highway excluded ($n = 55$, $R^2 = 0.602$)	
		β	p	β	p	β	p
Intercept		0.745	<0.001	0.707	<0.001	0.698	<0.001
Distance from nearest highway	km	−0.0254	0.004	−0.0252	0.003	−0.0264	0.007
Traffic count on nearest highway	vehicles day^{-1}	1.61×10^{-6}	0.003	1.89×10^{-6}	0.001	1.91×10^{-6}	0.001
Length of highways within 100 m	km	0.132	0.020				
Length of major roads within 100 m	km	0.138	0.021	0.112	0.047	0.127	0.033
Length of minor roads within 500 m	km	6.38×10^{-3}	0.112	6.51×10^{-3}	0.092	6.60×10^{-3}	0.108
Area of open space within 100 m	ha	−0.0272	0.097	−0.0283	0.063	−0.0324	0.043
Population density within 2000 m	dwellings km^{-2}	1.25×10^{-5}	0.043	1.33×10^{-5}	0.027	1.46×10^{-5}	0.022

Gilbert et al., 2007

Issues with outdoor LUR modeling

- Can you gather sufficient monitoring data for pollutants other than NO_2?
- Are the models physically interpretable and generalizable?
- Do they reasonably represent personal exposures?

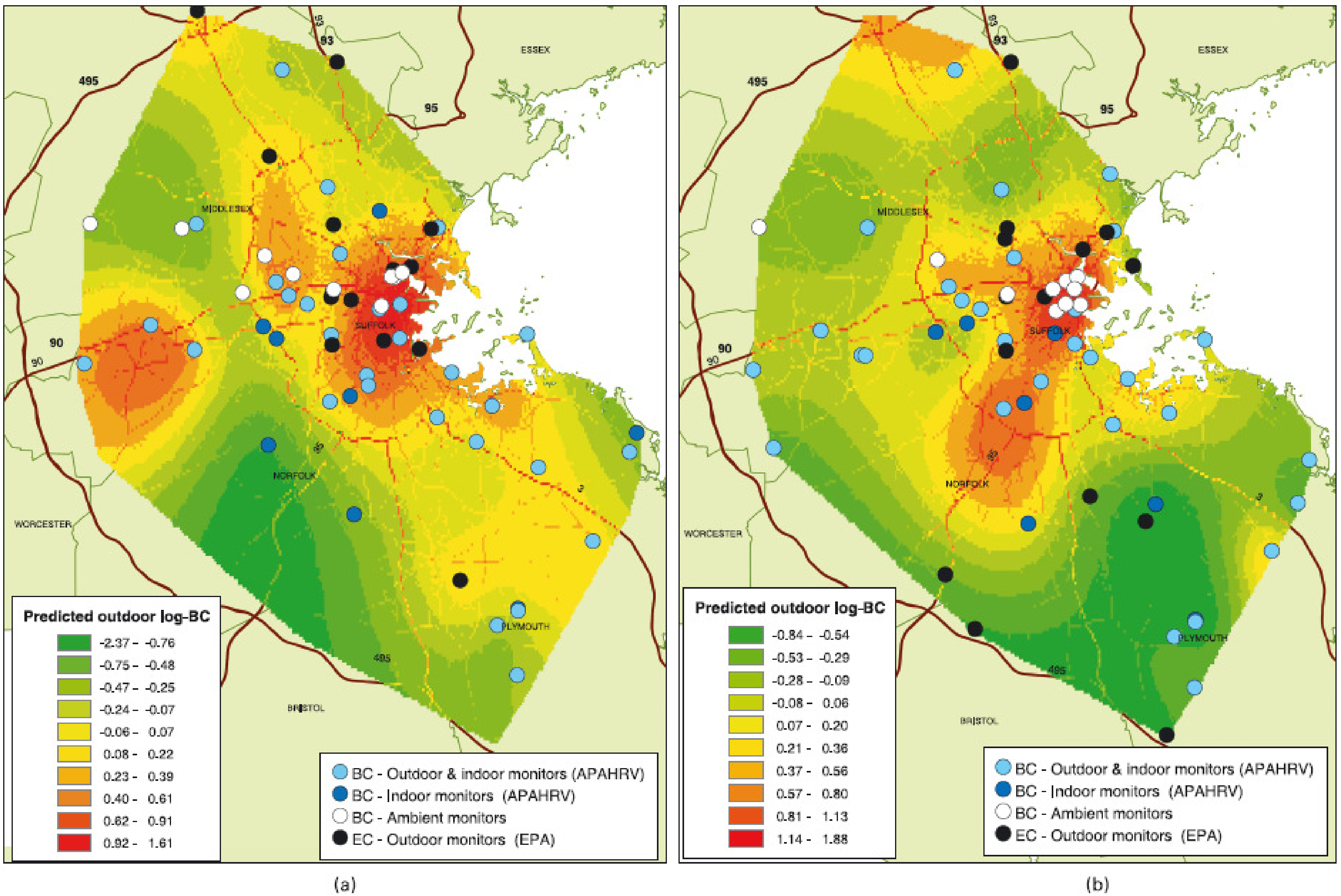


Fig. 4. Median predicted outdoor levels of BC for (a) winter and (b) summer: the winter predictions are for December 26th, 2002, and the summer predictions are for June 26th, 2002

Gryparis et al., 2007

Multi-pollutant LUR models

Predictor Type	Model	ln($PM_{2.5}$) (μg/m³) β (p-value)	Sequential R^2	Model	ln(EC) ($m^{-1}*10^{-5}$) β (p-value)	Sequential R^2	Model	NO_2 (ppb) β (p-value)	Sequential R^2
Intercept		0.205 *(.32)*	--		-0.907 *(<.0001)*	--		-12.50 *(.009)*	--
Central site Concentration	ln (Central Site [$PM_{2.5}$])	0.776 *(<.0001)*	.68	ln (Central site [EC])	0.103 *(.59)*	.03	Central site [NO_2]	1.06 *(<.0001)*	.21
				ln (Central site [EC]) * warmer season	0.82 (.004)	.26			
Traffic Indicator	Roadway Length in 100 m	$1.48*10^{-4}$ *(.02)*	.70	Roadway Length in 200 m	$1.10*10^{-4}$ *(.01)*	.40	Roadway Length in 50 m	0.0144 *(.002)*	.22
Traffic Indicator* Modifier	N/A	N/A	N/A	Roadway Length in 200 m × % Hours of Still Winds	$4.38*10^{-4}$ *(.02)*	.48	Roadway Length in 50 m × Obstructed Major Rd	-0.0094 *(.005)*	.31
Other Sources/ Land Use	Smoking or grilling	0.156 *(.01)*	.73	Warmer Season	-0.268 *(.057)*	.52	Warmer Season	4.93 *(.001)*	.44
	Population Density	$9.24*10^{-6}$ *(.01)*	.76				Population Density	$4.01*10^{-4}$ *(.001)*	.56

Clougherty et al., 2008

Outdoor vs. personal exposures

Study	Location	Season	Sampling Time	N	Fisher's Z-Transform	%<LOD**
Linn et al. (1996)	Southern California	All	1 day	107	Day's avg of children	NR*
Sarnat et al. (2001)	Baltimore	Summer	1 day	217	Individual	NR
Sarnat et al. (2001)	Baltimore	Winter	1 day	484	Individual	NR
Sarnat et al. (2005)	Boston	Summer	1 day	298	Individual	10.2
Sarnat et al. (2005)	Boston	Winter	1 day	341	Individual	2.2
Sarnat et al. (2006)	Steubenville	Summer	1 day	183	Individual	64.0
Sarnat et al. (2006)	Steubenville	Fall	1 day	228	Individual	15.0
Kim et al. (2006)	Toronto	All	1 day	15	Avg of individual correlations	NR

* Note: NR = Not reported
** Percent of data below detection limit
N = Number of observations

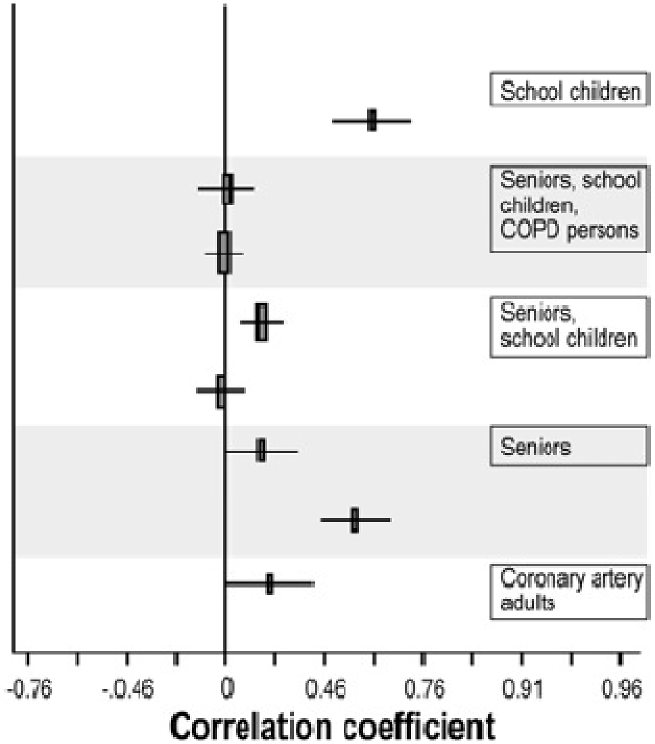


Figure 2.5-4. Distribution of correlation coefficients (U.S. studies) between personal NO_2 exposure and ambient NO_2 concentrations based on Fisher's Z transform.

EPA, 2008

Expanded LUR modeling

- Characterize indoor concentrations or personal exposures as a function of GIS variables, infiltration, indoor sources, etc.
- Likely to be closer to what people are actually exposed to (and further from simple proximity measures), but more complex to characterize

Indoor concentration LUR models

Table 5
Regression analyses of contributors to indoor concentrations accounting for the effect modification of open windows[a]

	R^2	Model	β (SE)	p-value
NO_2 (ppb)	0.25	Ambient concentrations	0.79 (0.35)	0.03
		Gas stove usage	6.8 (3.1)	0.04
		Unweighted density at 50 m buffer × open windows = Yes	0.07 (0.03)	0.01
		Unweighted density at 50 m buffer × open windows = No	−0.03 (0.06)	0.62
$PM_{2.5}$ ($\mu g\,m^{-3}$)	0.40	Ambient concentrations × open windows = Yes	0.98 (0.32)	<0.01
		Ambient concentrations × open windows = No	0.64 (0.32)	0.05
		Cooking time	6.2 (2.9)	0.04
		Occupant density	6.5 (2.3)	0.01
EC ($m^{-1} \times 10^{-5}$)	0.32	Ambient concentrations	0.38 (0.09)	<0.0001
		Distance to nearest designated truck route × open windows = Yes	-9.2×10^{-5} (4.1×10^{-5})	0.03
		Distance to nearest designated truck route × open windows = No	1.0×10^{-4} (5.9×10^{-5})	0.86

[a]Only significant interaction terms ($p<0.2$) are shown.

Baxter et al., 2007

Personal exposure LUR models

Table 6 – Percentage change (95% confidence interval) in personal measurements for exposure determinants that was significant in multiple regression mixed models

Variable influencing exposure	Change in variable[a]	Resulting percent change (95% confidence interval) in personal measured pollutant[b]			
		NO (%)	NO_2 (%)	ABS (%)	$PM_{2.2}$ (%)
Home gas stove	Yes (vs. no)	89 (58, 127)	44 (21, 70)	20 (5, 37)	35 (6, 70)
Home # of rooms	Increase of 1 room	–	−4 (−6, −1)	−3 (−5, −1)	−5 (−8, −2)
Home air conditioning	Yes (vs. no)	–	–	−41 (−59,−17)	−42 (−64, −7)
Outdoors	Increase of 1 h/day	−8 (−15, 1)	–	–	–
At/near home	Increase of 1 h/day	–	−3 (−5, −1)	–	–
Cooking with gas stove	Increase of 1 h/day	–	–	–	8 (0, 16)
Wood smoke tracer[c]	Log_{10} increase of 1 ng m^{-3}	–	–	38 (26, 50)	–
Traffic-based outdoor air pollution	NO = 25 ppb, NO_2 = 2.5 ppb	28 (14, 44)	11 (4, 19)	–	–
Monitor-based outdoor air pollution	NO = 15 ppb, $PM_{2.5}$ = 3.1 μg m^{-3}	19 (12, 26)	–	28 (21, 35)[d]	21 (12, 31)
Intercept		18.0 ppb	14.7 ppb	0.7 (m^{-1} 10^{-5})	8.5 μg m^{-3}

[a] Reported change in exposure determinant chosen for ease of interpretation (ie. 1 h/day or 1 room) for all home and activity variables, or using interquartile ranges for outdoor pollution levels.

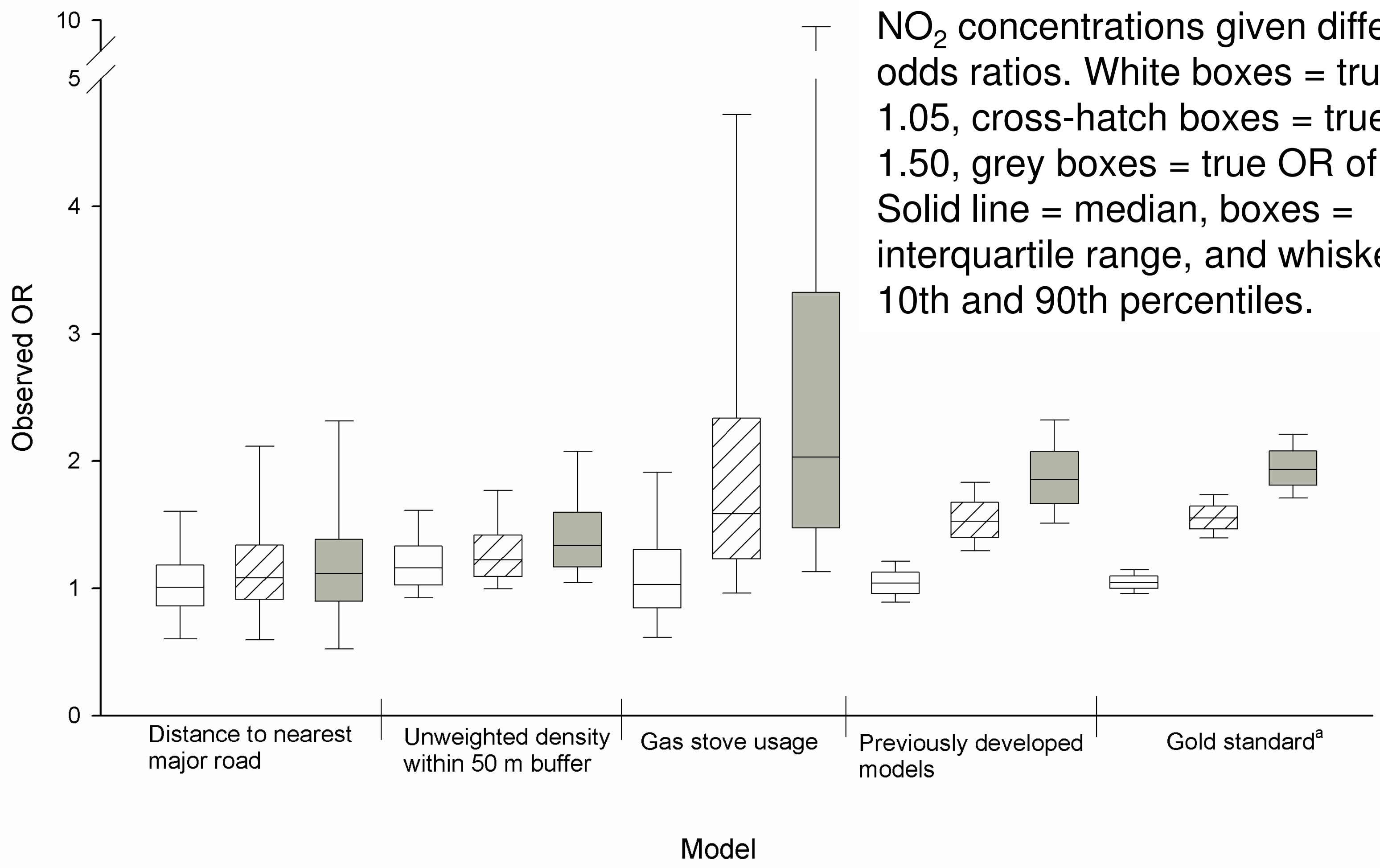
[b] – Indicates the variable was not significant in the final model for that pollutant.

[c] 'Wood smoke' refers to the levoglucosan concentration measured in personal samples.

[d] Monitor-based $PM_{2.5}$ was used in models for personal Absorbance because no outdoor Absorbance measurements are collected by the routine monitoring network.

Nethery et al., 2008

Why might this matter?



Distribution of estimated odds ratios per interquartile increase in NO_2 using various models of simulated indoor NO_2 concentrations given different true odds ratios. White boxes = true OR of 1.05, cross-hatch boxes = true OR of 1.50, grey boxes = true OR of 2.00. Solid line = median, boxes = interquartile range, and whiskers = 10th and 90th percentiles.

Baxter et al., 2009

Summary

- Near-roadway epidemiological literature to date has relied largely on measures with potentially significant exposure misclassification
  - Will tend to bias results to the null, though not always
  - Interpretation of measures will differ geographically
- Rapid expansion of LUR literature helping to develop more interpretable models, but significant resources needed to move to multi-pollutant personal exposures
- Atmospheric dispersion modeling can address multiple pollutants, but high spatial resolution is challenging

The NOx NAAQS

- Faces multiple challenges common for near-roadway exposures
  - Characterizing exposures given inadequate spatial density of monitors
  - Determining what associations are causal given high correlations
  - Establishing robust epidemiology given importance of indoor sources
- Many of these issues grappled with in 2008 ISA and REA

Current NOx monitoring (EPA, 2008)

Table 2-2. NOx Network Distribution across Measurement Scales.

Measurement Scale	**Number of Measurement Scale Records**	**Percent Distribution**
Microscale	3	0.78
Middle Scale	23	5.96
Neighborhood	212	54.92
Urban Scale	119	30.83
Regional Scale	29	7.51
Totals:	**386**	**100%**

Microscale -	0 to 100 meters
Middle Scale -	100 to 500 meters
Neighborhood Scale -	500 meters to 4 kilometers
Urban Scale -	4 to 50 kilometers
Regional Scale -	50 kilometers up to 1000km

NOx gradient literature

Location /season	Background	Traffic volume	Pollutant	Meteorology (wind speed/direction/stability)	Definition of spatial extent	Result
Canada/ September	Measurement upwind (west of) the highway	185,000 vehicles/day	NO_2	Wind from west	Major NO_2 decrease	**200m**
Zurich, Switzerland / November to January and June to August	Measurement at 20 m above ground	8,800 vehicles/day	NO_2		Percentage of maximum measured at the road	**Greater than or equal to 80m in the summer; less than 10% decrease over 80m in the winter**
South-west Sweden	Measurement 300m upwind (west of) the highway	18,900 to 32,500 vehicles/day)	NO_2	Wind from west	Contribution from highway becomes negligible	**500m**
Southern CA, US/ July to September	30m upwind from the highway	200,000 vehicles/day	NO	Wind speed 1.3-2.6m/s and directions within +- 45°arc sector of perpendicular to freeway	Less than 0.01 ppm influence on ambient measurement	**150-350m**
Southern CA, US/ July to September	30m upwind from the highway	200,000 vehicles/day	NO_2	Wind speed 1.3-2.6m/s and directions within +- 45°arc sector of perpendicular to freeway	Less than 0.01 ppm influence on ambient measurement	**500m**
Province of South Holland, the Netherlands /May to July	Most far away monitors at 260 to 305m*	80,000 to 152,000 vehicles/day	NO_2	High exposure if wind was within 60 degree from perpendicular to the road in the direction of the city district under study at least 33% of the time	Concentration gradient along distance	**110 to 165m**
Northern California, US/Spring and Fall	Schools upwind or more than 1000 m downwind from freeway	90,000 to 210,000 vehicles/day	NO_2, NO_x	Wind from west or southwest during the day, mean wind speed from 3 to 6 m/s	Concentration gradient along distance	**350m, mentioned the near traffic effects more pronounced for NO_x**
Scotland, UK/ 1 year	Sites farther away from the road	1,000 to 50,000 vehicles/day	NO_x	Prevailing south-westerly wind	Gradient of NO_x concentration and Ellenberg fertility indices of the vegetation communities	**>=11m**

Zhou and Levy, 2007

Causation or correlation?

Table 2.5-11. Pearson correlation coefficient between NO_X and traffic-generated pollutants.

SPECIES	ALL SITES	WITHOUT UPWIND OR BACKGROUND SITE
NO_X: $PM_{2.5}$ (motor vehicle component)	0.48<r<0.75[1]	0.48<r<0.75[2]
NO_X: CO	0.30<r<0.77[1]	0.54<r<0.77[2]
NO_X: Pb	0.42<r<0.76[1]	0.48<r<0.76[2]
NO_X: Br	0.55<r<0.73[1]	0.58<r<0.73[2]
NO_2: EC	0.93[3]	—
NO_2: EC	0.82 autumn, 0.24 summer[4]	—

[1]St. Louis RAPS (Kim et al., 2006), all sites
[2]St. Louis RAPS (Kim et al., 2006), all sites with upwind background site removed
[3]Ruhr Valley (Hochadel et al., 2006)
[4]Steubenville, OH (Sarnat et al., 2006)

EPA, 2008

Causation or correlation?

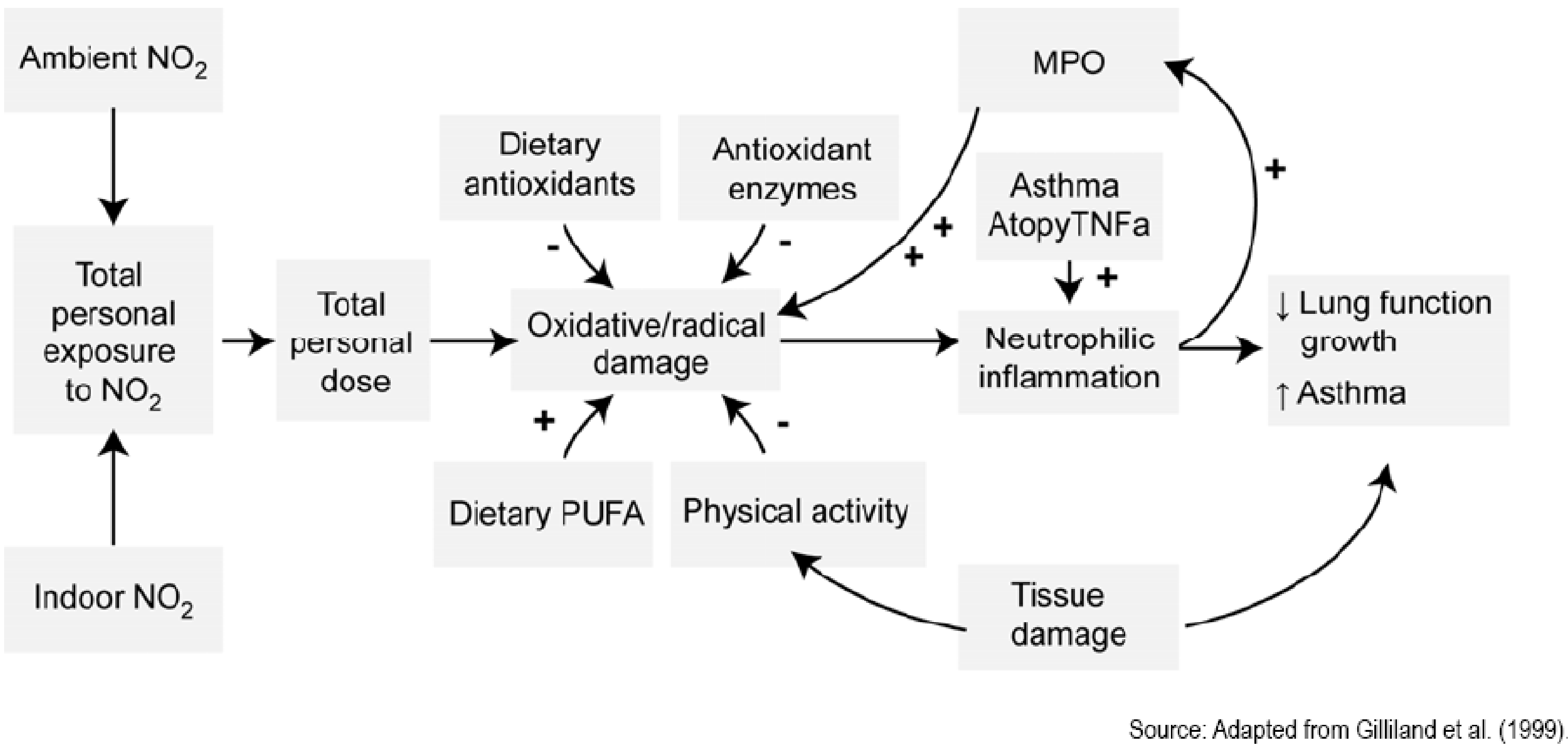
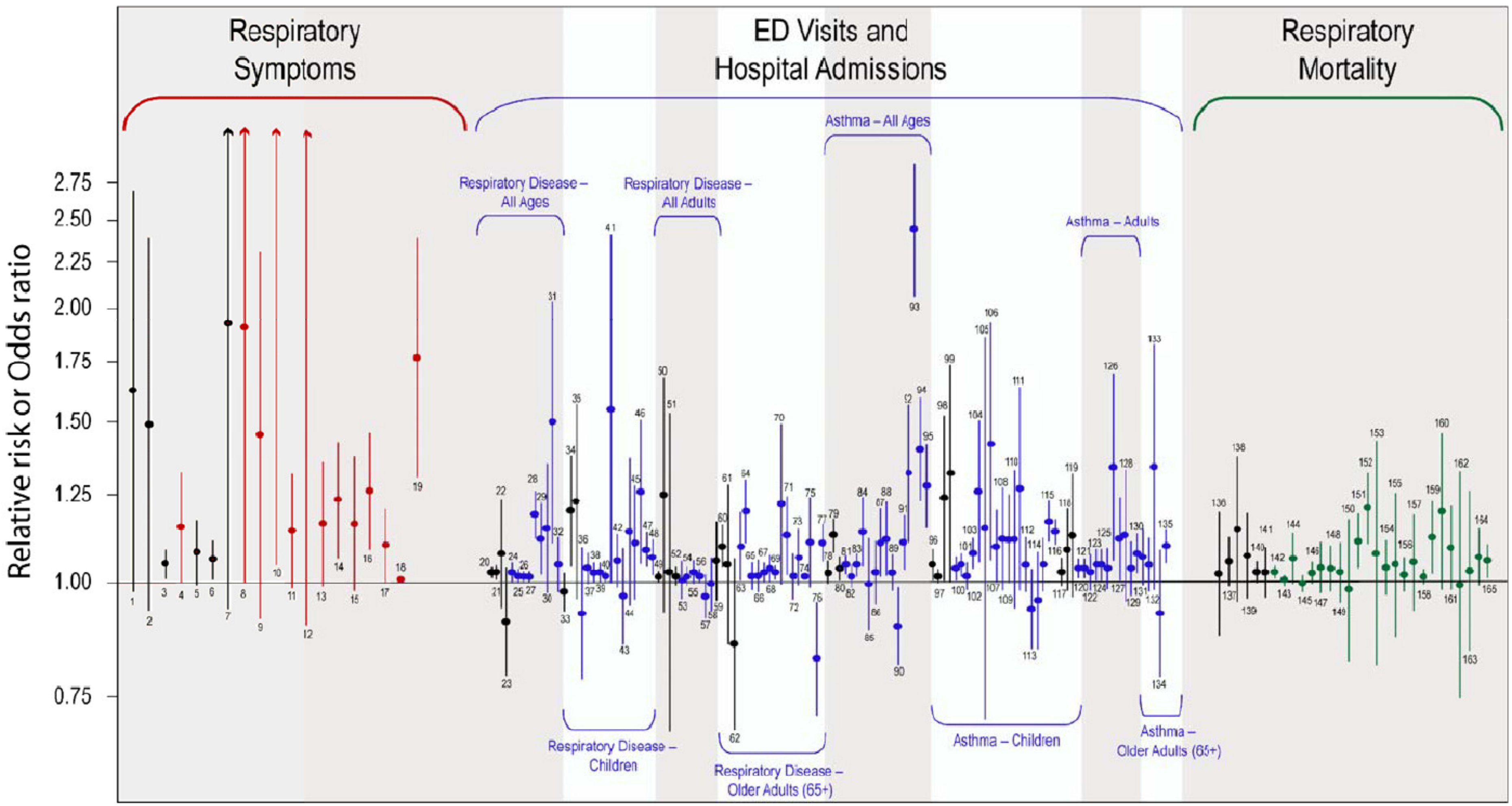


Figure 3.4-6. **Biological pathways of long-term NO_2 exposure on morbidity.**
MPO=myeloperoxidase; PUFA=polyunsaturated fatty acids; TNF-α=tumor necrosis factor-alpha.

EPA, 2008

Figure 5.3-1. Summary of epidemiologic studies examining short-term exposures to ambient NO_2 and respiratory outcomes.

Effect estimates for studies conducted in the U.S. or Canada are presented in black. Circles represent effect estimates. Lines represent 95% CI. Legend to figure on following page.



Federal Register observations (2009)

- Because monitors in the current network are not sited to measure peak roadway-associated NO_2 concentrations, individuals who spend time on and/or near major roadways could experience NO_2 concentrations that are considerably higher than indicated by monitors in the current area-wide NO_2 monitoring network.
- The EPA is proposing a two-tier network design to monitor ambient concentrations of NO_2 and assess compliance with the NO_2 NAAQS.

Summary re NOx NAAQS

- Proposed revisions hinge on near-roadway acute exposures, which have not been systematically characterized to date
- In spite of challenges given correlations with other near-roadway exposures, toxicological and chamber studies provide biological plausibility of NOx health effects
- Future monitoring should yield further insight about spatial patterns and hot spots

Future directions (I)

- "Near-roadway" includes many pollutants other than NOx with growing scientific evidence, including some not in the current regulatory domain
  - Ultrafine particle counts
  - Specific particle species/sources
- EPA ORD is embracing "source-to-outcome" paradigm in its Clean Air Research Program, using near-roadway as initial test case
  - Likelihood of multi-pollutant regulatory approaches related to near-roadway exposures

Future directions (II)

- Scientific literature will continue to develop refined exposure models (e.g., MESA-Air, studies using satellite data), which should help elucidate effects of low-level exposures
- With high spatiotemporal resolution concentration data, increasing need to develop good time-activity data, understanding of penetration efficiencies, etc.

Conclusions

- Literature clearly indicates health effects of near-roadway exposures, which overlap to some extent with literature on NAAQS pollutants but not entirely
  - Independent evidence supports health risks from NOx, ultrafine PM, traffic-related particle constituents, air toxics, etc.
  - Need for continued investigation to move beyond proximity measures to understand effects of specific pollutants