By Rachel Morello-Frosch, Miriam Zuk, Michael Jerrett, Bhavna Shamasunder, and Amy D. Kyle

Understanding The Cumulative Impacts Of Inequalities In Environmental Health: Implications For Policy

DOI: 10.1377/hlthaff.2011.0153
HEALTH AFFAIRS 30,
NO. 5 (2011): 879–887

ABSTRACT Racial or ethnic minority groups and low-income communities have poorer health outcomes than others. They are more frequently exposed to multiple environmental hazards and social stressors, including poverty, poor housing quality, and social inequality. Researchers are grappling with how best to characterize the cumulative effects of these hazards and stressors in order to help regulators and decision makers craft more-effective policies to address health and environmental disparities. In this article we synthesize the existing scientific evidence regarding the cumulative health implications of higher rates of exposure to environmental hazards, along with individual biological susceptibility and social vulnerability. We conclude that current environmental policy, which is focused narrowly on pollutants and their sources, should be broadened to take into account the cumulative impact of exposures and vulnerabilities encountered by people who live in neighborhoods consisting largely of racial or ethnic minorities or people of low socioeconomic status.

Rachel Morello-Frosch (rmf@berkeley.edu) is an associate professor in the Department of Environmental Science, Policy, and Management and in the School of Public Health at the University of California (UC), Berkeley.

Miriam Zuk is a graduate student in city and regional planning at UC Berkeley.

Michael Jerrett is an associate professor in the Division of Environmental Health Sciences at the School of Public Health, UC Berkeley.

Bhavna Shamasunder is a graduate student in the Department of Environmental Science, Policy, and Management at UC Berkeley.

Amy D. Kyle is an associate adjunct professor in the Division of Environmental Health Sciences, School of Public Health, UC Berkeley.

The persistence of health disparities and environmental inequalities in the United States has placed environmental health science and policy at a crossroads. Innovative scientific and regulatory approaches are needed to understand and address the cumulative, and potentially synergistic, effects of environmental and social stressors on the health of communities whose populations are mostly composed of racial or ethnic minorities or people of low socioeconomic status.

Advocates for such communities have long argued that their neighborhoods are beset by multiple environmental stressors, which could include air and water pollution and substandard housing. These community leaders also contend that existing regulations fail to protect residents adequately because the regulations are focused narrowly on pollutants and their sources.[1] Growing evidence shows that social stressors—including poverty, racial discrimination, crime, malnutrition, and substance abuse—also affect these communities.[2] Research is beginning to show how the cumulative effects of social and environmental stressors can work in combination to produce health disparities.[3]

With encouragement from scientists, policy makers, and environmental justice groups, regulatory agencies are beginning to consider the methodological challenges of addressing cumulative impacts in science and decision making.[4–6] These methodological challenges include how to evaluate and characterize the combined health effects of multiple environmental and social stressors on vulnerable populations, including the stressors' sources and the pathways of diseases. For example, the US Environmental Protection Agency has proposed a model for including psychological and social factors as integral components of cumulative risk assessment for predicting the potential health effects of pollu-

tion exposures in vulnerable populations.[7]

This article presents a synthesis of relevant research from the fields of social and environmental epidemiology, exposure assessment, and environmental justice. We believe that four key concepts underlie the emerging knowledge about the cumulative impacts of exposure to environmental hazards and social stressors.

First, health disparities between groups of different racial or ethnic makeup or socioeconomic status are significant and persistent, and exist for diseases that are linked to social and environmental factors. Second, inequalities in exposures to environmental hazards are also significant and persistent, and are linked to adverse health outcomes. Third, intrinsic biological and physiological factors—for example, age or genetic makeup—can modify the effects of environmental factors and contribute to differences in the frequency and severity of environmentally related disease. And fourth, extrinsic social vulnerability factors at the individual and community levels—such as race, sex, and socioeconomic status—may amplify the adverse effects of environmental hazards and can contribute to health disparities.

We highlight the evidence for these four concepts and conclude with a discussion of how this scientific foundation can help reshape regulatory science and decision making to reduce environmental health disparities and promote environmental justice among diverse communities.

Health Disparities

Research has documented systemic disparities in the incidence and severity of diseases between socioeconomic and racial or ethnic groups. A wide range of material, behavioral, psychosocial, environmental, and biological factors have been proposed to explain why social status is persistently linked to health.[2] Three health outcomes have been shown to be associated with both social and environmental stressors: adverse perinatal outcomes such as low birthweight and prematurity, cardiovascular disease, and self-rated health.

PERINATAL OUTCOMES African American infants are more likely to be delivered preterm and have low birthweight than white infants. These differences can result in higher risks of long-term health problems such as cognitive deficits, cardiovascular disease, and diabetes.[8] Socioeconomic and behavioral factors such as the mother's education, access to prenatal care, and substance use have been shown to contribute to poor perinatal outcomes—again, low birthweight and prematurity among them.[8] Research also indicates that prenatal stress resulting from maternal perceived discrimination, neighborhood deprivation, segregation, and income inequality are also linked to these poor perinatal outcomes, which suggests the importance of psychosocial pathways in the production of these racial or ethnic disparities.[9,10]

CARDIOVASCULAR DISEASE African Americans and people of low socioeconomic status have significantly higher rates of hypertension, heart disease, and stroke than whites and people of higher socioeconomic status.[11] Cardiovascular disease disparities have been linked to differences in biological risk factors such as diabetes, behavior such as physical inactivity, and the availability and use of primary and secondary preventive services.[12] Neighborhood environments have been linked to both the prevalence of heart disease and its risk factors.[13] Environmental pollutants, such as lead and ambient particulate matter—for example, extremely fine particles released into the air by vehicles and industrial plants that burn fossil fuels—have been linked to higher risk of cardiovascular disease.[14,15]

Emerging research has also linked the risk of developing cardiovascular disease in adulthood to early life events such as prenatal stress, which can disrupt development and cause heritable changes in gene expression. These so-called epigenetic changes can affect which genes are switched "on" or "off," which in turn can be associated with heightened disease risk.[16]

SELF-RATED HEALTH Self-rated health—a well-validated predictor of mortality, physical disability, chronic disease status, and health behavior[17]—is lower among racial and ethnic minorities and people of low socioeconomic status than others.[18] Researchers have found that racial disparities in self-rated health persist even after differences in socioeconomic status are controlled for.[19] The neighborhood people live in has been found to account for a large portion of the disparities between the way African Americans and whites rate their own health status.[20] This difference may be related to factors such as individual socioeconomic status, perceptions of neighborhood quality, health behavior, environmental quality, and psychosocial stress.[21]

Environmental Hazard Inequalities

Greater exposure to environmental hazards is one driver of health disparities found among communities of racial or ethnic minorities and those of low socioeconomic status. Research in this field has expanded from an initial focus on how close residents live to an environmental hazard, such as a highway or a major industrial facility, to encompass a broader investigation of

Poor communities suffer from a dearth of health-promoting resources.

the role that place plays in health. For example, a poor community populated by racial or ethnic minorities may also lack healthy food options,[22] high-quality green spaces, and recreational programs.[23] The lack of these positive factors can contribute to poor health.

PROXIMITY TO POLLUTING LAND USES AND TOXIC EMISSIONS Numerous studies have documented the disproportionate location of hazardous waste sites, industrial facilities, sewage treatment plants, and other locally undesirable and potentially polluting land uses in communities of racial or ethnic minorities and in socially disadvantaged neighborhoods.[24–26] Residents living near such facilities can be exposed to more pollutants than people who live in more affluent neighborhoods located farther from these sources of pollution.[27]

The residents of communities near industrial and hazardous waste sites experience an increased risk of adverse perinatal outcomes, respiratory and heart diseases, psychosocial stress, and mental health impacts.[28,29] Members of racial or ethnic minority groups and people of low socioeconomic status are also more likely than others to live near busy roads, where traffic-related air pollutants concentrate.[30] Research has linked a wide array of adverse health outcomes to residential proximity to traffic, including asthma,[31] low birthweight,[32] cardiovascular disease,[33] and premature mortality.[34]

EXPOSURES TO POLLUTANTS The poor and racial or ethnic minorities are disproportionately exposed to ambient air pollutants, which have been linked to respiratory and cardiovascular disease, adverse perinatal outcomes, diabetes, premature mortality, and other adverse effects.[35–38] Indoor environments also contribute to exposure disparities. Studies have found higher levels of indoor pollutants such as lead-based paint[39] and pollutants from industrial and transportation sources[40] in poor, African American, and Hispanic households than in other households.

Occupational exposures also constitute a source of environmental inequalities. For instance, Mexican American farm workers experience heightened exposure to organophosphate pesticides, which are associated with increased risk of cancer; preterm birth; and neurological, cardiovascular, and respiratory diseases.[41]

NEIGHBORHOOD ENVIRONMENTS Poor communities have an excess of health-damaging factors and a shortage of health-promoting amenities.[42] For example, residents of disadvantaged neighborhoods are exposed to more fast-food restaurants[43] and liquor stores than members of other communities. In particular, the presence of neighborhood liquor stores can influence health behavior and violence and can affect health both directly and indirectly.[44]

As noted above, poor communities also suffer from a dearth of health-promoting resources such as healthy food,[22] green spaces, and recreational programs,[23] whose lack can contribute to disparities in obesity rates and stress levels.[45,46] The confluence of these and other place-based factors contribute to the association between neighborhood socioeconomic status and adverse health outcomes.[20]

Intrinsic Factors: Biological Susceptibility

We use the term *susceptibility* to refer to intrinsic biological traits related to age, genetics, or preexisting health conditions that can create much variability in response to environmental stressors within a population.

AGE Children and the elderly experience heightened risk of pollution-related morbidity and mortality. The elderly are more susceptible to pollutant exposures because of their altered immune response and weakened respiratory and cardiovascular systems.[47] Children's susceptibility is associated with differences in rates of absorption, distribution, metabolism, and excretion of chemicals.[48] Exposure to stressors during childhood can greatly affect the development and functioning of organ systems well into adulthood.[49] Children have the potential for increased exposures to pollution because of their physical and behavioral activities, such as playing outside and frequent hand-to-mouth activity. Thus, their biological susceptibility combined with greater exposure to potentially toxic substances may put them at increased risk.

GENETICS AND GENE EXPRESSION Studies have found that certain genetic variants increase the effect of air pollution on respiratory symptoms, lung functioning, and asthma.[50] Where a child lives early in life, and the substances he or she is exposed to, can affect the development of disease in later life. These exposures may modify the patterns of gene expression—that is, turn genes "on" or "off"—which in turn triggers physiologic

changes and can potentially launch disease processes such as asthma or cancer.[16]

PREEXISTING HEALTH CONDITIONS Preexisting health conditions including diabetes, obesity, and cardiovascular disease can increase individual susceptibility to pollutant exposures. Studies have found that people with diabetes or a history of myocardial infarction are at heightened risk of cardiovascular morbidity and mortality associated with exposure to particulate matter.[51,52] In the United States, African Americans, Hispanics, and people of low socioeconomic status have higher rates of obesity, cardiovascular disease, and type 2 diabetes and are therefore more susceptible to environmental stressors.[11,53] Research is just beginning to link these disparities in preexisting conditions with neighborhood conditions.[45]

Extrinsic Factors: Social Vulnerability

We use the term *vulnerability* when describing how social constructs of race and class can amplify the effects of environmental exposures, with a focus on the pathway of psychosocial stress. We classify race as a social construct and not as a proxy for biological differences because research has consistently shown that race is a poor indicator for genetic variation in human populations and therefore should be understood as a social rather than biological category.[54]

Studies are uncovering the heightened vulnerability of people who belong to racial or ethnic minority groups or are of low socioeconomic status to environmental agents—a disparity that is not attributable to biological factors. Extrinsic factors that are socially related—such as race, ethnicity, socioeconomic status, and sex—can enhance the adverse effects of environmental exposures, such as short- and long-term exposures to air pollution.[55] Low neighborhood-level socioeconomic status may also amplify the risk of air pollution–related preterm births,[56] lower birthweight,[57] and adult mortality.[58]

Psychosocial pathways may link race and socioeconomic measures at the individual and area levels with the increased adverse impacts of environmental stressors. For example, studies indicate that exposure to violence and family stress increases the effects of traffic-related air pollution exposures on childhood asthma.[59,60] Low socioeconomic status and race or ethnicity have been linked to perceived stress as well as to biological markers of chronic stress.[61]

In addition to the direct effects of discrimination, social exclusion, and low socioeconomic status, the social and physical conditions of disadvantaged neighborhoods are also thought to contribute to psychosocial stress levels.[3] Researchers have proposed that the cumulative biological burden exacted by ongoing disruption of the body's stress-response system may explain the self-reinforcing effects or synergies observed among environmental and psychosocial stressors and may produce health disparities.[62,63]

Preexisting health conditions can increase individual susceptibility to pollutant exposures.

The cumulative physiological "wear and tear" resulting from chronic overactivity of the body's stress-response system may impair immune functioning and increase vulnerability to stressors[64] by increasing the absorption of toxicants into the body through increased respiration, perspiration, and consumption;[65] compromising the body's defense systems against toxicants; affecting the same physiological processes as environmental agents; and directly causing illness.[62]

Discussion

We have synthesized the scientific evidence underlying the cumulative impacts of environmental and social stressors and the multiple ways they can have a greater impact on communities of people who belong to racial or ethnic minority groups or are of low socioeconomic status. The four concepts of cumulative impacts that we outlined above have complex interrelationships and feedback loops (see the Appendix).[66]

Regulatory science and decision making must better integrate these four elements of cumulative impacts as a result of combined exposures, possible overlapping mechanisms and pathways for adverse health effects, and the potential for synergistic effects.[7] The National Research Council has also supported expanding scientific efforts to understand and address the multiple environmental and social stressors affecting community health.[67]

CUMULATIVE IMPACT ASSESSMENTS Regulatory agencies at the federal, state, and local levels are beginning to incorporate elements of cumulative impacts such as those described above into

The burden of proof is now placed on communities to demonstrate cumulative impacts.

assessment and planning procedures.[4,6] Nevertheless, the complexity of the task and the scarcity of scientific information and specific methodologies for assessing these cumulative effects have limited the scope of this work to date.[67]

One important challenge is how to characterize and mathematically model the interactions among environmental and social stressors, sources, pathways, and routes. Researchers are beginning to develop indices for aggregating environmental and social stressors. For example, Jason Su and colleagues developed an index to characterize social inequities in the cumulative effects of multiple air pollutants from both mobile and stationary sources at the regional level.[68] Still, the work to develop more sophisticated tools for assessing cumulative impacts and environmental disparities is in its infancy, and investigators are uncertain about the best way to cumulate and deal with interactions and overlapping components or pathways.

Fundamental to further work in this area is the need to better incorporate vulnerability into environmental health research, assessments, policies, and actions.[1] Current risk assessment practices address differential susceptibility for certain intrinsic biological factors (for example, age) by applying safety or default factors to protect biologically sensitive populations (such as children) in limited cases. However, the environmental risk assessment process does not apply such approaches to extrinsic factors—including neighborhood poverty, unemployment, lack of food security, and other psychosocial stressors—that can contribute to the heightened vulnerability of disadvantaged communities).[1,7,67] One potential reason for this omission is the persistent debate over pathways linking social vulnerability to environmental exposures. Researchers have established many dimensions of social vulnerability such as human and political capital, discrimination, and features of the built environment,[2] which should be taken into account in environmental health research and assessment practices.

Health impact assessment is an interdisciplinary approach to assessing the consequences of proposed policies, plans, and projects. This type of assessment features an explicit concern for socially excluded or vulnerable populations and uses a combination of quantitative, qualitative, and participatory techniques.[68–70] Health impact assessment may provide a promising path for incorporating cumulative impacts into assessments to guide decision making.

By considering together the baseline environmental conditions, health status, and vulnerabilities of the communities potentially affected by decisions, health impact assessments have the potential to address the complex causal pathways through which decisions can affect health.[71] Compared to risk assessment, which is mostly quantitative, health impact assessment is better able to deal with a scarcity of scientific information because it uses a diverse array of evidence for analysis—for example, epidemiological evidence along with qualitative observations of neighborhood social conditions and physical environments.

The inclusion of a broader array of evidence may result in more efficient and proactive measures than risk assessments, which rely heavily on toxicological evidence.[71,72] A key challenge, however, will be systematically integrating the health impact assessment process into environmental regulation and decision making.

POLICIES TO ADDRESS CUMULATIVE IMPACTS

The evidence that environmental and social stressors converge in disadvantaged communities and that residential context plays an important and independent role in health disparities indicates the need for targeted place-based and proactive approaches to policy making. One approach is to use cumulative impact screening to map, characterize, and target vulnerable communities for interventions that improve existing conditions and prevent future harm.[1]

The burden of proof is now placed on communities to demonstrate cumulative impacts, yet many disadvantaged neighborhoods may lack political clout or the capacity for civic engagement to push for regulatory action. The use of cumulative impact screening could remove this burden of proof from vulnerable communities and increase the likelihood that disadvantaged neighborhoods will receive focused regulatory attention.

Several agencies, such as the Environmental Protection Agency, are beginning to develop such tools to target enforcement and compliance activities nationally,[73] guide land use planning in California,[74] and inform regulatory programs at the California Air Resources Board.[75] As with health impact assessments, a critical issue will

be the linkage between assessments and the decision making authorities of the agencies.

Progressive approaches coming from local governments can provide some guidance for ways to systematically address cumulative impacts in vulnerable communities. The Environmental Justice Ordinance in Cincinnati, Ohio, for instance, requires new or expanding industrial facilities to demonstrate that they will not cause a "cumulative adverse impact" to the health and environment of the community in order to receive a permit.[76]

Similarly, Los Angeles is considering a "green zones" ordinance, which would use cumulative impact screening to guide municipal planning, the issuing of permits, and enforcement strategies to mitigate and reduce environmental hazards in disproportionately affected neighborhoods.[77,78] Such strategies could provide a more place-based, holistic, and proactive approach to environmental protection.

Conclusion

Communities of racial or ethnic minorities or people of low socioeconomic status are particularly vulnerable to environmental and social stressors. More holistic and transparent approaches to the regulatory science underlying decision making that affects such communities are needed. Screening methods can help regulators and policy makers more efficiently target efforts to remediate the cumulative effects of these exposures and environmental inequities, and to focus regulatory action at the neighborhood and regional levels. Because industrial and transportation development, as well as other land-use planning decisions, are often rooted within metropolitan regions and neighborhoods, regulatory interventions to mitigate the cumulative impact of environmental and social stressors on the health of disadvantaged communities will require multilevel, placed-based strategies.[79] ■

This work was funded in part by the California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (07-E0009, Understanding and Acting on Cumulative Impacts on California Communities) and the Superfund Research Program of the National Institute of Environmental Health Sciences. The authors thank Valerie Tran for assistance with preparing this manuscript.

NOTES

1 National Environmental Justice Advisory Council. Ensuring risk reduction in communities with multiple stressors: environmental justice and cumulative risks/impacts. Washington (DC): The Council; 2004.

2 Adler NE, Rehkopf DH. US disparities in health: descriptions, causes, and mechanisms. Annu Rev Public Health. 2008;29:235–52.

3 Clougherty J, Kubzansky L. A framework for examining social stress and susceptibility in air pollution and respiratory health. Environ Health Perspect. 2009;117(9):1351–8.

4 Environmental Protection Agency. Framework for cumulative risk assessment. Washington (DC): EPA; 2003.

5 National Environmental Justice Advisory Council. Nationally consistent environmental justice screening approaches. Washington (DC): The Council; 2010.

6 Office of Environmental Health Hazard Assessment. Environmental justice activities at OEHHA: cumulative impacts and precautionary approaches [Internet]. Sacramento (CA): California Environmental Protection Agency; 2007 [cited 2011 Mar 31]. Available from: http://oehha.ca.gov/ej/index.html

7 DeFur PL, Evans GW, Cohen Hubal EA, Kyle AD, Morello-Frosch RA, Williams DR. Vulnerability as a function of individual and group resources in cumulative risk assessment. Environ Health Perspect. 2007;115(5):817–24.

8 Giscombe CL, Lobel M. Explaining disproportionately high rates of adverse birth outcomes among African Americans: the impact of stress, racism, and related factors in pregnancy. Psychol Bull. 2005;131(5):662–83.

9 Mustillo S, Krieger N, Gunderson EP, Sidney S, McCreath H, Kiefe CI. Self-reported experiences of racial discrimination and black-white differences in preterm and low-birthweight deliveries: the CARDIA study. Am J Public Health. 2004;94(12):2125–31.

10 Huynh M, Parker JD, Harper S, Pamuk E, Schoendorf KC. Contextual effect of income inequality on birth outcomes. Int J Epidemiol. 2005;34(4):888–95.

11 Mensah GA, Mokdad AH, Ford ES, Greenlund KJ, Croft JB. State of disparities in cardiovascular health in the United States. Circulation. 2005;111(10):1233–41.

12 Kaplan GA, Keil JE. Socioeconomic factors and cardiovascular disease: a review of the literature. Circulation. 1993;88(4):1973–98.

13 Diez-Roux AV, Nieto FJ, Muntaner C, Tyroler HA, Comstock GW, Shahar E, et al. Neighborhood environments and coronary heart disease: a multilevel analysis. Am J Epidemiol. 1997;146(1):48–63.

14 Navas-Acien A, Guallar E, Silbergeld E, Rothenberg SJ. Lead exposure and cardiovascular disease—a systematic review. Environ Health Perspect. 2007;115(3):472–82.

15 Pope CA 3rd, Burnett RT, Krewski D, Jerrett M, Shi Y, Calle EE, et al. Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke: shape of the exposure-response relationship. Circulation. 2009;120(11):941–8.

16 Kuzawa CW, Sweet E. Epigenetics and the embodiment of race: developmental origins of US racial disparities in cardiovascular health. Am J Human Biol. 2009;21(1):2–15.

17 Idler E, Benyamini Y. Self-rated health and mortality: a review of twenty-seven community studies. J Health Soc Behav. 1997;38:21–37.

18 Yao L, Robert SA. The contributions of race, individual socioeconomic status, and neighborhood socioeconomic context on the self-rated health trajectories and mortality of older adults. Res Aging. 2008;30(2):251–73.

19 Subramanian SV, Acevedo-Garcia D, Osypuk TL. Racial residential segregation and geographic heterogeneity in black/white disparity in poor self-rated health in the US: a multilevel statistical analysis. Soc Sci Med. 2005;60(8):1667–79.

20 Do DP, Finch BK, Basurto-Davila R, Bird C, Escarce J, Lurie N. Does place

explain racial health disparities? Quantifying the contribution of residential context to the black/white health gap in the United States. Soc Sci Med. 2008;67(8):1258–68.
21 Wen M, Hawkley LC, Cacioppo JT. Objective and perceived neighborhood environment, individual SES and psychosocial factors, and self-rated health: an analysis of older adults in Cook County, Illinois. Soc Sci Med. 2006;63(10):2575–90.
22 Morland K, Filomena S. Disparities in the availability of fruits and vegetables between racially segregated urban neighbourhoods. Public Health Nutr. 2007;10(12):1481–9.
23 Dahmann N, Wolch J, Joassart-Marcelli P, Reynolds K, Jerrett M. The active city? Disparities in provision of urban public recreation resources. Health Place. 2009; 16(3):431–45.
24 Mohai P, Lanz PM, Morenoff J, House JS, Mero RP. Racial and socioeconomic disparities in residential proximity to polluting industrial facilities: evidence from the Americans' Changing Lives Study. Am J Public Health. 2009; 99(Suppl 3):S649–56.
25 Mohai P, Saha R. Racial inequality in the distribution of hazardous waste: a national-level reassessment. Soc Probl. 2007;54(3):343–70.
26 Morello-Frosch R, Pastor M Jr., Porras C, Sadd J. Environmental justice and regional inequality in southern California: implications for future research. Environ Health Perspect. 2002;110(Suppl 2): 149–54.
27 Morello-Frosch RA. Discrimination and the political economy of environmental inequality. Environ Planning C: Govern Policy. 2002; 20(4):477–96.
28 Vrijheid M. Health effects of residence near hazardous waste landfill sites: a review of epidemiologic literature. Environ Health Perspect. 2000;108:101–12.
29 Downey L, Willigen MV. Environmental stressors: the mental health impacts of living near industrial activity. J Health Soc Behav. 2005; 46(3):289–305.
30 Gunier RB, Hertz A, von Behren J, Reynolds P. Traffic density in California: socioeconomic and ethnic differences among potentially exposed children. J Expo Anal Environ Epidemiol. 2003;13(3):240–6.
31 Gauderman WJ, Avol E, Lurmann F, Kuenzli N, Gilliland F, Peters J, et al. Childhood asthma and exposure to traffic and nitrogen dioxide. Epidemiology. 2005;16(6):737–43.
32 Wilhelm M, Ritz B. Residential proximity to traffic and adverse birth outcomes in Los Angeles County, California, 1994–1996. Environ Health Perspect. 2003;111(2): 207–16.
33 Künzli N, Jerrett M, Garcia-Esteban R, Basagaña X, Beckermann B, Gilliland F, et al. Ambient air pollution and the progression of atherosclerosis in adults. PLoS ONE. 2010; 5(2):e9096.
34 Jerrett M, Finkelstein M, Brook J, Arain M, Kanaroglou P, Stieb D, et al. A cohort study of traffic-related air pollution and mortality in Toronto, Ontario, Canada. Environ Health Perspect. 2009;117(5):772–7.
35 Brook RD, Jerrett M, Brook JR, Bard RL, Finkelstein MM. The relationship between diabetes mellitus and traffic-related air pollution. J Occup Environ Med. 2008;50(1):32–8.
36 Brunekreef B, Holgate ST. Air pollution and health. Lancet. 2002; 360(9341):1233–42.
37 Jerrett M, Burnett RT, Kanaroglou P, Eyles J, Finkelstein N, Giovis C, et al. A GIS-environmental justice analysis of particulate air pollution in Hamilton, Canada. Environment and Planning A. 2001;33:955–73.
38 Woodruff TJ, Parker JD, Kyle AD, Schoendorf KC. Disparities in exposure to air pollution during pregnancy. Environ Health Perspect. 2003;111(7):942–6.
39 Jones RL, Homa DM, Meyer PA, Brody DJ, Caldwell KL, Pirkle JL, et al. Trends in blood lead levels and blood lead testing among US children aged 1 to 5 years, 1988–2004. Pediatrics. 2009;123(3):e376–85.
40 Brody JG, Morello-Frosch R, Zota A, Brown P, Pérez C, Rudel RA. Linking exposure assessment science with policy objectives for environmental justice and breast cancer advocacy: the Northern California Household Exposure Study. Am J Public Health. 2009;99(Suppl 3):S600–9.
41 Eskenazi B, Bradman A, Castorina R. Exposures of children to organophosphate pesticides and their potential adverse health effects. Environ Health Perspect. 1999;107: 409–19.
42 Teutsch S, Fielding J. Applying comparative effectiveness research to public and population health initiatives. Health Aff (Millwood). 2011;30(2):349–55.
43 Kwate NO, Yau CY, Loh JM, Williams D. Inequality in obesigenic environments: fast food density in New York City. Health Place. 2009;15(1): 364–73.
44 Wright RJ, Steinbach SF. Violence: an unrecognized environmental exposure that may contribute to greater asthma morbidity in high risk inner-city populations. Environ Health Perspect. 2001;109(10): 1085–9.
45 Gordon-Larsen P, Nelson MC, Page P, Popkin BM. Inequality in the built environment underlies key health disparities in physical activity and obesity. Pediatrics. 2006;117(2): 417–24.
46 Hartig T. Green space, psychological restoration, and health inequality. Lancet. 2008;372(9650):1614–5.
47 Sandström T, Frew AJ, Svartengren M, Viegi G. The need for a focus on air pollution research in the elderly. Eur Respir J Suppl. 2003;40:92s–5s.
48 Faustman EM, Silbernagel SM, Fenske RA, Burbacher TM, Ponce RA. Mechanisms underlying children's susceptibility to environmental toxicants. Environ Health Perspect. 2000;108:13–21.
49 Gavidia TG, Pronczuk de Garbino J, Sly PD. Children's environmental health: an under-recognised area in paediatric health care. BMC Pediatr. 2009;9:10.
50 Yang IA, Fong KM, Zimmerman PV, Holgate ST, Holloway JW. Genetic susceptibility to the respiratory effects of air pollution. Thorax. 2008; 63(6):555–63.
51 Zanobetti A, Schwartz J. Are diabetics more susceptible to the health effects of airborne particles? Am J Respir Crit Care Med. 2001; 164(5):831–3.
52 Zanobetti A, Schwartz J, Gold D. Are there sensitive subgroups for the effects of airborne particles? Environ Health Perspect. 2000;108(9): 841–5.
53 Wang Y, Beydoun MA. The obesity epidemic in the United States—gender, age, socioeconomic, racial/ethnic, and geographic characteristics: a systematic review and meta-regression analysis. Epidemiol Rev. 2007;29:6–28.
54 Krieger N. Stormy weather: race, gene expression, and the science of health disparities. Am J Public Health. 2005;95(12):2155–60.
55 O'Neill MS, Jerrett M, Kawachi I, Levy JI, Cohen AJ, Gouveia N, et al. Health, wealth, and air pollution: advancing theory and methods. Environ Health Perspect. 2003;111(16): 1861–70.
56 Ponce NA, Hoggatt KJ, Wilhelm M, Ritz B. Preterm birth: the interaction of traffic-related air pollution with economic hardship in Los Angeles neighborhoods. Am J Epidemiol. 2005;162(2):140–8.
57 Morello-Frosch R, Jesdale B, Sadd J, Pastor M. Ambient air pollution exposure and full-term birth weight in California. Environ Health. 2010; 9:44.
58 Finkelstein MM, Jerrett M, DeLuca P, Finkelstein N, Verma DK, Chapman K, et al. Relation between income, air pollution, and mortality: a cohort study. CMAJ. 2003;169(5): 397–402.
59 Clougherty JE, Levy JI, Kubzansky LD, Ryan PB, Suglia SF, Canner MJ, et al. Synergistic effects of traffic-related air pollution and exposure to violence on urban asthma etiology. Environ Health Perspect. 2007; 115(8):1140–6.
60 Shankardass K, McConnell R, Jerrett M, Milam J, Richardson J, Berhane K. Parental stress increases the effect

of traffic-related air pollution on childhood asthma incidence. Proc Natl Acad Sci U S A. 2009;106(30):12406–11.
61 Goodman E, McEwen BS, Huang B, Dolan LM, Adler NE. Social inequalities in biomarkers of cardiovascular risk in adolescence. Psychosom Med. 2005;67(1):9–15.
62 Gee G, Payne-Sturges D. Environmental health disparities: a framework integrating psychosocial and environmental concepts. Environ Health Perspect. 2004;112(17):645–53.
63 Morello-Frosch R, Shenassa ED. The environmental "riskscape" and social inequality: implications for explaining maternal and child health disparities. Environ Health Perspect. 2006;114(8):1150–3.
64 McEwen BS. Protective and damaging effects of stress mediators. N Engl J Med. 1998;338(3):171–9.
65 Gordon CJ. Role of environmental stress in the physiological response to chemical toxicants. Environ Res. 2003;92(1):1–7.
66 To access the Appendix, click on the Appendix link in the box to the right of the article online.
67 National Research Council Committee on Improving Risk Analysis Approaches Used by the US EPA. Science and decisions: advancing risk assessment. Washington (DC): National Academies Press; 2009.
68 Su J, Morello-Frosch R, Jesdale B, Kyle AD, Shamasunder B, Jerrett M. An index for assessing demographic inequalities in cumulative environmental hazards with application to Los Angeles, California. Environ Sci Technol. 2009;43(20):7626–34.
69 Cole BL, Wilhelm M, Long PV, Fielding JE, Kominski G, Morgenstern H. Prospects for health impact assessment in the United States: new and improved environmental impact assessment or something different? J Health Polit Policy Law. 2004;29(6):1153–86.
70 Corburn J, Bhatia R. Health impact assessment in San Francisco: incorporating the social determinants of health into environmental planning. J Environ Plann Man. 2007;50(3):323–41.
71 Bhatia R. A guide for health impact assessment [Internet]. San Francisco (CA): Department of Public Health; 2009 [cited 2011 Apr 1]. (Working draft provided for review and use by the California Department of Public Health). Available from: http://www.arb.ca.gov/cc/ab32publichealth/meetings/091409/hia_guidelines_sept_04_09.pdf
72 Levy J. Is epidemiology the key to cumulative risk assessment? Risk Anal. 2008;28(6):1507–13.
73 Environmental Protection Agency. The Environmental Justice Strategic Enforcement Assessment Tool (EJSEAT) [Internet]. Washington (DC): EPA; 2011 Mar 15 [cited 2011 Apr 1]. Available from: http://www.epa.gov/environmentaljustice/resources/policy/ej-seat.html
74 California Air Resources Board. Air quality and land use handbook: a community health perspective. Sacramento (CA): The Board; 2005.
75 Pastor M Jr., Morello-Frosch R, Sadd J. Air pollution and environmental justice: integrating indicators of cumulative impact and socio-economic vulnerability into regulatory decision-making [Internet]. Sacramento (CA): California Air Resources Board; 2010 [cited 2011 Apr 1]. (Final Report, Contract No.: 04-308). Available from: http://www.arb.ca.gov/research/apr/past/04-308.pdf
76 City of Cincinnati. Ordinance 210—2009 [Internet]. Cincinnati (OH): City of Cincinnati; 2009 Jun 29 [cited 2011 Apr 29]. Available from: http://www.vorysenergy.com/uploads/file/26337.pdf
77 Osborn B. News from the frontlines: L.A. poised to deal with hidden hazards. Liberty Hill [blog on the Internet]. 2011 Jan 21 [cited 2011 Apr 1]. Available from: http://libertyhill.typepad.com/main/2011/01/la-poised-to-deal-with-hidden-hazards.html
78 Sahagun L. Turning toxic hotspots green. Los Angeles Times. 2011 Jan 21.
79 Pastor M, Dreir P, Grigsby J, Lopez-Garza M. Regions that work: how cities and suburbs can grow together. Minneapolis (MN): University of Minnesota Press; 2000.

ABOUT THE AUTHORS: RACHEL MORELLO-FROSCH, MIRIAM ZUK, MICHAEL JERRETT, BHAVNA SHAMASUNDER & AMY D. KYLE

Rachel Morello-Frosch is an associate professor at the University of California, Berkeley.

In this issue of *Health Affairs*, Rachel Morello-Frosch and coauthors make the case that regulators need to consider the cumulative effects of various environmental and social stressors on poorer communities or those populated by racial and ethnic minorities. It's not enough to look just at the impact of exposure to a particular chemical, for example. Studies have found that chronic social stress, such as being poor or being discriminated against racially, can make individuals and communities more vulnerable to environmental hazards.

Yet "policy makers have been slow to respond to the scientific evidence," Morello-Frosch says. She hopes that this article will encourage them to take a broader view of the causes of health concerns and look into the cumulative effect of various stressors.

Morello-Frosch is an associate professor at the University of California (UC), Berkeley, in both the Department of Environmental Science, Policy, and Management and the School of Public Health. She received both her doctoral degree in environmental health sciences and her master of public health degree in epidemiology and biostatistics from UC Berkeley. In 2010 she was awarded the American Public Health Association's Damu Smith environmental health achievement award.

Miriam Zuk is a graduate student in city and regional planning at UC Berkeley.

Miriam Zuk is a doctoral candidate in city and regional planning at the University of California, Berkeley.

Michael Jerrett is an associate professor in the Division of Environmental Health Sciences at the UC Berkeley School of Public Health. He received both his doctorate in geography and his master's degree in political science from the University of Toronto. In 2010 he was appointed to the National Academies Committee on Human and Environmental Exposure Science in the Twenty-First Century.

Bhavna Shamasunder is a graduate student in the Department of Environmental Science, Policy, and Management at UC Berkeley.

Bhavna Shamasunder expects to receive her doctoral degree from the Department of Environmental Science, Policy, and Management at UC Berkeley in May 2011.

Amy Kyle is an associate adjunct professor in environmental health sciences at the UC Berkeley School of Public Health. She received both her doctorate in environmental health sciences and her master of public health degree from UC Berkeley.