Exhibit 5

Declaration of Professor Steven B. Wing, Ph.D.

<u>**DECLARATION OF STEVE WING**</u>

I, Steve Wing, do hereby declare as follows:

1. My full name is Steven Bennett Wing. I am of legal age and competent to give this declaration. All of the information herein is based on my own personal knowledge unless otherwise indicated.

2. From 1985 to present, I have been a faculty member in the Department of Epidemiology at The University of North Carolina at Chapel Hill. I am currently an Associate Professor. A copy of my Curriculum Vitae is attached as **Exhibit 1**.

3. Since 1996, my research has focused on the impact of swine confinement facilities, also known as confined animal feeding operations ("CAFOs"), on the well-being and quality of life of workers and neighboring residents. As is evident in my CV, my research in this area has been extensively published in peer-reviewed journals.

4. I submit this declaration to aid in the environmental review of the C&H hog CAFO located in Mount Judea, Arkansas. Evidence regarding the harmful impacts of hog CAFO airborne emissions on human health and quality of life should be considered in this review. Here I describe much of this evidence, focusing on research I have collaborated on concerning impacts of swine CAFO air emissions. I also describe some of the research I have collaborated on regarding water quality impacts from CAFOs.

Background

5. A large hog CAFO produces as much fecal matter and urine as a city of 50,000 or more people but, unlike a city, has no wastewater treatment plant. Instead, animal wastes are flushed into open cesspools and then sprayed on nearby fields. *See* Steve Wing, *Environmental Injustice Connects Local Food Environments with Global Food Production, in* Local Food

Environments: Food Access in America 63, 63-84 & fig.3.1 (Kimberly B. Morland, ed. 2015) (attached as **Exhibit 2**). Industrial-scale animal waste sprayers capable of dispersing hundreds of gallons of waste per minute create mists that can easily drift downwind into neighboring communities. *Id.* fig.3.2. Hog CAFOs emit gases and particles from confinements, open cesspools, sprayfields, and bins of rotting carcasses that are stored on site prior to disposal.

6. Air pollution from hog CAFOs harms human health. Particles less than 10 microns in aerodynamic diameter (PM_{10}), including endotoxins, bacteria, yeasts, and molds that are recognized toxins and inflammatory mediators, can be inhaled deep into the respiratory tract. Hog CAFO gases can affect both the upper and lower respiratory tract. Hydrogen sulfide, a toxic compound produced by anaerobic decomposition of hog waste, travels off-site through the air to nearby communities. Ammonia, which can irritate the eyes and mucous membranes, is also released by hog CAFOs. Humans absorb gaseous ammonia in the upper respiratory tract. When transformed into fine particles in the presence of humidity, ammonia can reach deeper into the lungs.

7. Hog CAFOs emit a large number of volatile organic compounds that contribute to the offensive odors described by neighbors. These compounds may occur as gases or may be adsorbed to fine particles. When fine particles are inhaled and settle onto the warm, moist mucous membranes of the nose, they release odorant compounds that are detected by the olfactory nerves. Airborne emissions from hog CAFOs thus have pronounced impacts on the health and quality of life of neighbors.

Key Research Related to Impacts of CAFO Air Emissions

8. An extensive body of peer-reviewed scientific evidence shows that hog CAFOs contaminate the air in neighboring communities and that this air contamination affects the health

and quality of life of neighbors. A bibliography of some of the key scientific literature is attached as **Exhibit 3**.

9. I am part of a research group consisting of university faculty members, doctoral student research assistants, university research staff, members of community-based organizations, and government scientists that has conducted numerous studies of the community impacts of hog CAFOs. We have focused our research on the eastern portion of North Carolina, a state in which hog CAFOs are permitted to store waste in open-air lagoons, as I understand the C&H facility does. Our research and findings in North Carolina about the community impacts of large hog CAFOs are relevant to the analysis of the potential impacts that the C&H facility may have on the surrounding community and environment.

10. With support from the North Carolina Department of Health and Human Services and the National Institute of Environmental Health Sciences, our research group conducted a survey of health and quality of life of residents of three eastern North Carolina communities with similar demographic and economic characteristics. The results of this study were published in *Environmental Health Perspectives*, the peer-reviewed scientific journal of the National Institute of Environmental Health Sciences, National Institutes of Health, United States Department of Health and Human Services. *See* Steve Wing & Susanne Wolf, *Intensive Livestock Operations, Health, and Quality of Life among Eastern North Carolina Residents*, 108 Envtl. Health Perspectives 233 (2000) (**Exhibit 4**). Of the three communities surveyed, one had no industrial livestock facilities, another had two cattle operations, and in the third, residents lived within two miles of a hog CAFO. Residents living near the hog CAFO reported higher frequencies of headache, runny nose, sore throat, coughing, diarrhea, and burning eyes compared to residents of the community with no industrial livestock production. To evaluate quality of life, we asked

participants how often in the past six months they were unable to open their windows or go outside even in nice weather. Hog CAFO neighbors reported an average of 18.5 days in the past six months when they couldn't open their windows, and 15.4 days when they couldn't go outside, compared to 3.2 and 2.1 days, respectively, in the community with no livestock production. This demonstrates the extent to which hog CAFOs affect the quality of the environment for nearby communities.

11. I have also conducted research focused specifically on the impacts of hog CAFOs on nearby schools and the health of children attending those schools. The findings from the study described in this paragraph were published in *Pediatrics*, the peer-reviewed journal of the American Academy of Pediatrics. *See* Maria C. Mirabelli et al., *Asthma Symptoms among Adolescents who Attend Public Schools that are Located near Confined Swine Feeding Operations*, 118 Pediatrics e66 (2006) (attached as **Exhibit 5**). During the 1999-2000 school year, the North Carolina Department of Health and Human Services conducted a survey of respiratory symptoms, asthma diagnoses, and asthma treatment among public middle school students across the State. Because this survey did not include an evaluation of environmental exposures that could affect children's respiratory heath, our research team sent a questionnaire to rural school staff to assess environmental exposures, including the frequency of occurrence of livestock odors at the schools. We hypothesized that, because respiratory irritants and allergens are present in air emissions from hog and poultry CAFOs, asthma symptoms would be more prevalent among children who attended schools affected by livestock air pollution. The survey results supported our hypothesis. We found that children who attended schools where staff reported livestock odor inside school buildings twice or more per month had a 23% higher prevalence of wheezing symptoms compared to children who attended schools where no

livestock odor was reported. Our study showed that children attending schools within three miles of a hog CAFO had more asthma-related symptoms, more doctor-diagnosed asthma, and more asthma-related medical visits compared to students who attended schools further away.

12. From 2003 until 2005, our research group conducted a repeated-measures study of air pollution, health, and quality of life in 16 neighborhoods in eastern North Carolina. The neighborhoods, located in three different counties, were located within 1.5 miles of at least one and up to 16 hog CAFOs. For two to three weeks, we monitored concentrations of PM_{10} and hydrogen sulfide at a central location in each neighborhood. *See* Ex. 2, Fig. 3.10. While we monitored air pollution, adult non-smokers living around the monitors participated in a study of health and quality of life. Participants had their odor sensitivity tested and chose times each morning and evening when they agreed to sit on their porch for 10 minutes to be exposed to the ambient air. For two to three weeks, twice a day, they used a structured diary to rate the strength of hog odor from none to very strong, rate their experience of respiratory symptoms and irritation of the eyes and nose, report disruption of routine activities of daily living, measure their lung function, and measure their blood pressure. *See id.*, Fig. 3.9. One hundred and one study participants produced over 2,900 journal entries. This study was designed to evaluate the acute effects of hog CAFO air pollution on neighbors. Rather than comparing exposed communities to unexposed communities in another location, we compared participants' symptoms, quality of life, lung function, and blood pressure at times when they were exposed and times when they were unexposed. Thus, each person served as her or his own control. Unlike comparisons between exposed and unexposed communities, which can be affected by differences between groups in medical history, diet, weight, occupational exposure, housing, and other attributes, these other potential influences on health are essentially the same for a person for the two to

three weeks of the study when they experienced time periods of higher versus lower hog CAFO pollution.

13. As detailed in one of our resulting papers, which was published by the peer-reviewed scientific journal *Environmental Health Perspectives*, study participants reported hog odor outside their homes on more than half of days in the study and inside their homes on 12.5% of days. *See* Steve Wing et al., *Air Pollution and Odor in Communities Near Industrial Swine Operations*, 116 Envtl. Health Perspectives 1362 (2008) (attached as **Exhibit 6**). Reported hog odor and measured hydrogen sulfide concentrations were highest in the mornings and evenings—times when people commonly like to engage in outdoor activities at home. Participant reports of hog odor were strongly related to ambient concentrations of hydrogen sulfide and to levels of fine particles at higher wind speeds (particles travel further in the wind than when the air is still). The correspondence between participants' hog odor ratings and pollutant concentrations measured by air monitors provides objective validation of participants' odor ratings.

14. During the two-to-three weeks of the study, approximately one-third of participants reported cancelling or changing daily activities due to hog odor. As we explained in our paper, "[t]ypical changes included closing windows, avoiding sitting in the yard and socializing with friends, cancelling plans to barbecue, not putting clothes out to dry, declining exercise via outdoor walks, not putting up Christmas lights, not being able to garden or mow the lawn, not washing the car, or not being able to sit on the porch." *See id.* Participants reported cancelling or changing their daily activities 11.3 times more often when average odor in the past 12 hours was rated as 5 or greater on the 0-8 scale compared to times when average odor was less than 1. Evidently, hog CAFO odors were highly disruptive of daily activities in this

population, despite the fact that three-quarters of participants indicated they grew up on a farm where they had experience with livestock odors.

15. There is considerable evidence documenting the psychological impact of malodor. In the case of odors from hog CAFOs, a broad range of mood impacts has been of interest. Authors of the first published study of impacts of hog CAFO odor on North Carolina residents concluded that, "[p]ersons living near the intensive swine operations who experienced the odors reported significantly more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects." *See* Susan S. Schiffman et al., *The Effect of Environmental Odors Emanating from Commercial Swine Operations on the Mood of Nearby Residents*, 37 Brain Research Bulletin 369 (1995) (attached as **Exhibit 7**).

16. As part of the repeated-measures study described in paragraph 12 above, our research group evaluated hog odor and measured pollutants as triggers of stress and negative mood. The *American Journal of Public Health*, the peer-reviewed scientific journal of the American Public Health Association, published our findings. *See* Rachel Avery Horton et al., *Malodor as a Trigger of Stress and Negative Mood in Neighbors of Industrial Hog Operations*, 99 Am. J. of Pub. Health (Supplement 3) S610 (2009) (attached as **Exhibit 8**). Participants reported feeling more stressed or annoyed, nervous or anxious, gloomy or unhappy, angry or grouchy, and confused or unable to concentrate, during times when hog odors were stronger. Participants also reported higher levels of stress and annoyance during times when air pollution monitoring instruments showed that concentrations of hydrogen sulfide and semi-volatile PM_{10} were higher in their neighborhoods.

17. Our repeated-measures study further showed that, in addition to having psychological effects on humans, odorant chemicals have physiological effects. These findings

were published in *Environmental Health Perspectives*. *See* Steve Wing et al., *Air Pollution from Industrial Swine Operations and Blood Pressure of Neighboring Residents*, 121 Envtl. Health Perspectives 92 (2013) (attached as **Exhibit 9**). Participants in the study described in paragraph 12 measured their blood pressure after sitting outdoors for 10 minutes. To limit the possibility of errors in recording blood pressure values, each participant printed their blood pressure readings with a time stamp and pasted the print-outs in their diaries. Participants' diastolic blood pressures were higher at times when they reported stronger hog odor outside their homes than when there was less odor. Their systolic blood pressures rose with the concentrations of hydrogen sulfide, measured in a central location in their neighborhoods at the time they sat outside. In addition to providing an objective measure of people's physiological response to odorant compounds that cause annoyance, physical symptoms, and disruption of daily activities, repeated acute elevations of blood pressure are a medical concern due to their potential to contribute to chronic hypertension.

18. Consistent with well-documented effects of ammonia, PM_{10}, and volatile organic compounds, as well as prior reports of human impacts of air pollution from hog CAFOs, the repeated-measures study described in paragraph 12 demonstrated that individuals experienced physical as well as mental discomfort in the presence of hog CAFO air pollution. *Epidemiology*, the peer-reviewed journal of the International Society for Environmental Epidemiology, published these findings. *See* Leah Schinasi et al., *Air Pollution, Lung Function, and Physical Symptoms in Communities Near Concentrated Swine Feeding Operations*, 22 Epidemiology 208 (2011) (attached as **Exhibit 10**). After sitting outside for 10 minutes at their selected morning and evening times, participants reported more irritation of the eyes, nose, throat, and skin and more coughing when hog odor was stronger compared to when it was weaker or absent. Eye

irritation was related to concentrations of hydrogen sulfide and PM_{10}. One or more respiratory symptoms were related to hydrogen sulfide, components of PM_{10}, endotoxin, and odor. A measure of lung function, forced expiratory volume in one second, which participants took following their ten-minute outdoor exposure, declined with increasing average concentrations of fine particles ($PM_{2.5}$) in the past 12 hours. These physical effects of exposure to airborne emissions from hog CAFOs help explain the stress and annoyance experienced by hog CAFO neighbors.

19. Research based on qualitative interviews can help elucidate the influence of social factors in environmental health research. Our research group therefore designed a study using in-depth interviews. After completing the repeated-measures study described in paragraph 12, 42 participants and seven other volunteers from the same neighborhoods participated in semi-structured interviews designed to obtain information about how odor from the hog CAFOs in their neighborhoods affected their enjoyment of life and beneficial use of property. The interviews were recorded and transcribed, and codes were assigned to participants' responses. The peer-reviewed journal, *New Solutions: A Journal of Environmental and Occupational Health Policy*, published our findings. *See* Mansoureh Tajik et al., *Impact of Odor from Industrial Hog Operations on Daily Living Activities*, 18 New Solutions 193 (2008) (attached as **Exhibit 11**). This study found that hog CAFO odors impact neighbors' ability to engage in activities they enjoy the most and that they expect to be able to do inside and outside their homes. These include "cookouts, barbequing, family reunions, socializing with neighbors, gardening, working outside, playing, drying laundry outside, opening doors and windows for fresh air and to conserve energy, use of well water, and growing vegetables." *Id.* We concluded that "[t]he types of activities that are restricted by hog odor are social interactions, physical

activities, energy- and cost-saving activities, relaxing outside or indoors, and sleeping." *Id.* We further noted that restriction of these activities is important because they "have been shown to positively affect health, improve overall well-being, reduce stress, and strengthen social networks." *Id.*

Key Research Related to Impacts of Hog CAFOs on Water Quality

20. Liquid contaminants from hog CAFOs are released to the environment through leakage from animal waste pits, runoff from land application of liquid wastes, atmospheric deposition (e.g. through rainfall), and failure of the earthen walls of waste pits. Parasites, bacteria, viruses, nitrates, and other components of liquid hog CAFO waste pose threats to human health.

21. In 2010, our research group conducted a study of fecal contamination of streams in an area of eastern North Carolina with a high density of hog CAFOs. *Science of the Total Environment*, an international peer-reviewed journal for scientific research into the environment and its relationship with humankind, published this research. *See* Christopher D. Heaney et al., *Source Tracking Swine Fecal Waste in Surface Water Proximal to Swine Concentrated Animal Feeding Operations*, 511 Science of the Total Environment 676 (2015) (attached as **Exhibit 12**). In many samples, we found elevated levels of fecal indicator bacteria. To determine whether fecal contamination of these streams could be traced to nearby hog CAFOs, we evaluated several candidate microbial source tracking markers. Microbial source tracking markers use DNA from microorganisms that have become adapted to the gastrointestinal tracts of particular species of animals, making them useful for identifying the type of animal that is responsible for fecal contamination. We found that two candidate markers, *Bacteroidales* Pig-1-Bac and Pig-2-Bac, were present in 80% and 87%, respectively, of hog waste and wallow water samples, but were

absent in chicken, turkey, goat, horse, cow, and human fecal samples. We found Pig-1-Bac and Pig-2-Bac to be more prevalent in samples taken downstream compared to upstream locations near hog CAFOs, and we found that their prevalence increased following rain events that can transport fecal waste from hog CAFO sprayfields into streams. This study provides direct evidence that hog CAFOs contaminate nearby streams during routine operations.

22. Routine air and water pollution from hog CAFOs can be contrasted with pollution that occurs following storms. Overflow of waste pits during heavy rain events results in massive spills of animal waste into neighboring communities and waterways. For example, our research group identified 237 hog CAFOs with permit coordinates that were located in flooded areas identified from satellite imagery taken approximately one week after Hurricane Floyd hit eastern North Carolina in September, 1999. These findings were published in *Environmental Health Perspectives*. *See* Sacoby M. Wilson et al., *Environmental Injustice and the Mississippi Hog Industry*, 110 Envtl. Health Perspectives (supplement 2) 195 (2002) (attached as **Exhibit 13**).

23. As my research and extensive scientific literature shows, hog CAFOs release toxic air and water pollution into surrounding neighborhoods where it directly impacts the health and well-being of neighbors. In North Carolina, the affected communities are disproportionately composed of low-income people of color who have fewer protections from environmental hazards, less ability to leave their homes during high exposure periods, and less access to medical and clinical services than residents of higher income communities; these factors increase their vulnerability to the harmful impacts of hog CAFO emissions. This evidence is consistent with evaluations of CAFO impacts in other locations and understanding of the increased vulnerability of low-income populations, including low-income people near the C&H CAFO, to environmental hazards. For all the reasons stated above, I believe it is crucial for a credible

environmental review of the C&H hog CAFO to evaluate impacts of hog CAFOs on air quality, quality of life, and human health.

I declare under the penalty of perjury that the foregoing is true and correct.

EXECUTED this _3rd_ day of September, 2015 in Chapel Hill, North Carolina.

Steve Wing

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Steve Wing

Exhibit 1 to the
Declaration of Professor Steven B. Wing, Ph.D.

CURRICULUM VITAE

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EDUCATION

University of North Carolina Chapel Hill, NC	Ph.D. in Epidemiology 1983
Duke University Durham, NC	M.A. in Sociology 1980
Vassar College Poughkeepsie, NY	B.A. in Psychology 1975

PROFESSIONAL EXPERIENCE

1995- Associate Professor, Department of Epidemiology, University of North Carolina, Chapel Hill.

1993 Visiting Professor, Department of Preventive Medicine, Federal University of Bahia, Salvador, Brazil.

1991-95 Assistant Professor, Department of Epidemiology, University of North Carolina, Chapel Hill.

1990 Visiting Professor, Faculty of Theoretical Medicine, University of Ulm, Germany.

1985-91 Research Assistant Professor, Department of Epidemiology, University of North Carolina.

1983-85 Post-doctoral Fellow, Department of Epidemiology, University of North Carolina, Chapel Hill.

FELLOWSHIPS AND HONORS

2014	John E. Larsh, Jr. Award for Mentorship, University of North Carolina School of Public Health
2014	Self-Determination Award, Black Workers for Justice
2011	Homer N. Calver Award, Environment Section, American Public Health Association
2009	International Society for Environmental Epidemiology Research Integrity Award
2004	Bernard G. Greenberg Alumni Endowment Award for Outstanding Teaching, Service and Practice, University of North Carolina School of Public Health
2003	Certificate of Honor, Alliance for Nuclear Accountability
1997	A Man Called Mathew Award, Concerned Citizens of Tillery and Land Loss Fund
1993	Brazilian National Research Council Visiting Professor Fellowship
1983-85	National Heart, Lung and Blood Institute Post-doctoral Traineeship
1983	Delta Omega, National Honorary Public Health Society
1981-83	National Heart, Lung and Blood Institute Pre-doctoral Traineeship
1980-81	United States Public Health Service Pre-doctoral Traineeship
1978-80	National Institute for General Medical Sciences Pre-doctoral Traineeship

PUBLICATIONS (*indicates first author was an advisee when the work was conducted)

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<u>Letters, invited commentaries and book review in peer-reviewed journals</u>

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<u>Monographs, non-refereed journal articles, and other published works</u>

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Wing S. Justica ambiental, ciencia y salud pública. *Salud y Medio Ambiente*, 37:35-45, 2009. (translation of 2005 article from *Essays on the Future of Environmental Health Research*)

Aitken M, Crump C, Heaney C, Lowman A, McDonald P, Wing S. Epidemiologic Surveillance and Investigation of Symptoms of Illness Reported By Neighbors of Biosolids Land Application Sites. Report to Water Environment Research Foundation, 2008.

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Wing S, Richardson D. Material Living Conditions and Health in the United States, Canada and Western Europe. Research in Public Health Technical Papers, Series 19, Pan American Health Organization, Washington, DC, 2000.

Wing S, Richardson D. Occupational Health Studies at Los Alamos National Laboratory. In, New Mexico's Right to Know: The Impacts of LANL Operations on Public Health and the Environment, Concerned Citizens for Nuclear Safety, 2002, http://www.nuclearactive.org.

Wing S. Evaluation of the US Agency for Toxic Substances and Disease Registry's Public Health Assessment of Laurence Livermore National Laboratory. Prepared for Tri-Valley CAREs, Western States Legal Foundation and the San Francisco Bay Area Physicians for Social Responsibility under their "Health Consultation on the Impact of Two Major Tritium Accidents at Livermore Lab: An Independent Scientific Analysis," 2002.

Invited scientific lectures, seminars and testimony

Health inequalities, industrial agriculture, and the Civil Rights Act of 1964. Joe G. Lopez Lectureship on Racial Disparities in Health, Boston University School of Public Health, October 29, 2014.

Reification of chance in epidemiology and society. Department of Public Health Sciences Medical University of South Carolina, March 21, 2014.

Epidemiologic studies of radiation releases from nuclear facilities. New York Academy of Medicine, March 11, 2013.

Poverty, health, and industrial hog production. Committee to Advance Science Writing, New Horizons in Science, Raleigh, NC October 28, 2012.

Social and ecological dimensions of the food supply: health inequalities. Exploring the True Costs of Food, Institute of Medicine, April 23-24, 2012

Environmental health and the corporate-government alliance. Homer N. Calver Award Lecture, Environment Section, American Public Health Association annual meeting, Washington, DC, October 31, 2011.

Cancer risks near nuclear facilities: The importance of research design and explicit study hypotheses. National Academy of Sciences Committee on Analysis of Cancer Risks Near Nuclear Facilities, Atlanta, GA, May 23, 2011.

Public health research and the environmental justice movement. Doris Slesinger Lecture, Department of Community and Environmental Sociology and Department of Family Medicine. University of Wisconsin, Madison, March 30, 2011.

Radiation health effects: The case of plutonium. Rocky Mountain Peace and Justice Center and Department of Environmental Studies, Naropa University, Boulder, CO, March 31, 2011.

Air pollution from swine CAFOs and health of neighboring communities. Departmental Seminar, Department of Environmental Health, Johns Hopkins University. December 8, 2010.

The scope of epidemiology. Expert workshop on cancer in Basrah, Iraq. Istanbul, November 17, 2010.

Swine CAFOs, air pollution, and community health. Evaluating the Health Effects to Local Communities of Confined Animal Feeding Operations (CAFOs) Workshop. NC State University, November 11, 2010.

Developing testable hypotheses for cancer risks near nuclear power facilities. Nuclear and Radiation Studies Board, National Academy of Sciences, Washington, DC, April 26, 2010.

What kind of action comes from research? (with Gary Grant). Partnerships for Environmental Public Health Program Meeting, Research Triangle Park, NC, April 26, 2010.

Research and Data Needs for Assessing and Addressing Disproportionate Environmental Health Impacts Among Minority and Disadvantaged Populations. (Panelist) US Environmental Protection Agency, Strengthening Environmental Justice and Decision Making: A Symposium on the Science of Disproportionate Environmental Health Impacts. Washington DC, March 17 - 19, 2010

Environment, disasters, and health disparities. Minority Health Conference, University of North Carolina, Chapel Hill, February 27, 2009.

Cancer around nuclear power plants: Collision of evidence and assumptions, déjà vu. Meeting of the Society for Radiation Protection, Virchow Clinic Campus, Medical University of Berlin, September 28, 2008.

Assumptions, evidence, and causal reasoning in radiation epidemiology. Annual meeting of the German Society for Epidemiology, Bielefeld, Germany, September 27, 2008.

Improving environmental health science through community-driven research. University of Texas Medical Branch Sealy Center for Environmental Health and Medicine, Galveston, TX, March 31, 2008 (with Gary Grant).

Integrating Epidemiology with Community Action for Environmental Justice. Department of Environmental Health Sciences, UNC Chapel Hill, March 19, 2008.

Whose science, whose environmental health? Fronteers in Environmental Science Series, National Institute of Environmental Health Sciences, Research Triangle Park, NC, September 14, 2007.

Changing views of the biological effects of low-level ionizing radiation. Royal Society of Medicine, London, International Physicians for Prevention of Nuclear War, October 3, 2007.

Research partnerships for public health and environmental justice. Jensen Lecture, Duke University Department of Sociology, April 7, 2006

Public health preparedness, disease control, and social justice. Rock Ethics Institute, Health as a Human Right Lecture, Pennsylvania State University, October 17, 2005.

Health disparities. American Medical Association – Medical Student Section Region 4 Annual Meeting, Duke University Medical Center, March 5, 2005.

Genes, justice, and racial inequalities in health. 5th Annual Minority Health Leadership Summit, School of Public Health, University of Pittsburgh, January 13, 2005.

Quantitative methods in the epidemiology of environmental injustice: Examples from eastern North Carolina. Math Departmental Seminar, East Carolina University, December 1, 2004.

Improving environmental health science through partnerships in communities affected by environmental injustice. The Science of Environmental Justice Working Conference, US Environmental Protection Agency, Boston University, May 25, 2004.

North Carolina swine production, health and environmental justice (with Gary R. Grant). The Science of Environmental Justice Working Conference, US Environmental Protection Agency, Boston University, May 26, 2004.

Environmental injustice in eastern North Carolina: Corporate hogs and guerrilla epidemiology. Department of Epidemiology and Biostatistics seminar, College of Public Health, University of South Florida, December 3, 2003.

Inequality and inequity: the broader causes of health disparities. Panel presentation, Mending the Health Care Divide: Eliminating Disparities in Access for Minority and Low Income Communities. University of North Carolina School of Law, UNC Center for Civil Rights and UNC School of Public Health, Chapel Hill, NC, November 1, 2003.

The "chilling effect" on environmental health research: Industry tactics and institutional disincentives. Conflicted Science: Corporate Influence on Scientific Research and Science-Based Policy, conference sponsored by the Center for Science in the Public Interest's Integrity in Science Project. July 11, 2003 Washington, DC.

Science, objectivity and ethics in environmental health. Dialogues for Improving Research Ethics in Envrionmental and Public Health (Conference), Brown University, Providence, RI, May 31, 2003.

Methodology and ethics in epidemiology of environmental justice: Industrial hogs and guerrilla epidemiology. Departmental Seminar, Department of Epidemiology, School of Public Health, State University of New York, Albany, NC, April 11, 2003.

Health disparities, research ethics and environmental epidemiology. Epidemiology Branch, National Institute of Environmental Health Sciences, May 13, 2002.

Health impacts, Risks and Response: Nuclear Terrorism in the Triangle, A Public Forum to Address Emergency Planning and Risk Minimization, sponsored by Orange and Chatham County Boards of Commissioners, William Friday Center, Chapel Hill, NC, May 2, 2002.

Bioterrorism preparedness and health disparities, The New War Economy, a teach-in sponsored by the UNC-CH Progressive Faculty Network, Chapel Hill, NC, April 19, 2002.

The role of epidemiology in evaluating releases from nuclear facilities: Insights from the work of Alice Stewart. The Alice Stewart Lecture, 16th Low Level Radiation and Health Conference, Dublin Institute of Technology, Ireland, June 21, 2002.

Health effects of low level radiation, Physicians for Social Responsibility, Los Angeles, March 11, 2002.

Community based environmental health research, Morehouse College and Southeast Community Research Center, Atlanta, GA, November 10, 2001.

Pork production, public health and environmental justice. Department of Environmental Health, University of Cincinnati, Departmental Seminar, May 23, 2001.

Subcommittee on Energy and Environment of the Committee on Science, United States House of Representatives, "Reexamining the Scientific Basis for the Linear No-Threshold Model of Low-dose Radiation," July 18, 2000. Published testimony: Serial No. 106-98, pages 101-115 and 123-138. Government Printing Office, Washington, DC: 2001.

Human Health, Sustainable Hog Farming Summit, New Bern, NC, January 11, 2001.

Integrating research, teaching and practice in environmental justice. Departmental Seminar, Department of Sociology and Anthropology, NC State University, December 1, 2000.

Community public health needs and industrial animal production research. American Public Health Association Annual Meeting, Boston, MA, November 14, 2000.

Social inequalities in occupational and environmental health. Brazilian Congress of Epidemiology Annual Meeting, Salvador, Bahia, Brazil, September 1, 2000.

The influence of age at exposure to radiation on cancer risk in humans. American Statistical Association Conference on Radiation and Health, Park City, UT, June 27, 2000.

National Academy of Sciences, Committee on the Biological Effects of Ionizing Radiation (BEIR VII). "The Relevance of Occupational Epidemiology to Radiation Protection Standards," Washington DC, June 13, 2000.

Radiation and Rocky Flats: Risks to workers and the public, Rocky Mountain Peace and Justice Center, Boulder, CO, June 24, 2000.

Public health and intensive hog production in North Carolina. Research Triangle Institute, June 9, 2000.

Low level radiation and health. Brookhaven National Laboratory, June 5, 2000.

Research to action: Getting our work used! Community-Based Research for Environmental Justice: Workshops from the Field 2000 Training and Conference, Rutgers University, Newark, NJ, May 21, 2000.

Health effects of nuclear weapons production, Our Nuclear Future, Conference held prior to the United Nations Disarmament Conference, United Nations Plaza Hotel, New York, NY, April 24, 2000.

US Environmental Protection Agency National Environmental Justice Advisory Committee, Enforcement Subcommittee, "Confined animal feeding operations," Atlanta, GA, May 25, 2000.

The challenge of environmental justice: Science, public health and advocacy, Minority Health Conference, School of Public Health, Chapel Hill, NC, February 18, 2000.

Environmental health effects of intensive livestock operations. Division of Occupational and Environmental Medicine departmental seminar, School of Medicine, Duke University, February 8, 2000.

United States Department of Agriculture Air Quality Task Force. "Health and intensive livestock operations," Research Triangle Park, NC, November 1, 1999.

Environmental injustice in North Carolina's hog industry. Regional Research Institute Colloquium, West Virginia University, Morganton, WV, October 8, 1999.

Community based research and environmental justice, African American Environmental Justice Action Network Conference, Arlington, VA, September 18, 1999.

Agriculture Committee, House of Representatives, North Carolina General Assembly, "Environmental Injustice in North Carolina's Hog Industry, " Raleigh, NC, April 27, 1999.

Intensive livestock operations, health, and quality of life among eastern North Carolina residents. Conference on Public Health Impacts of Intensive Livestock Operations, NC Department of Health and Human Services, Raleigh, NC, July 15, 1999.

Radiation and health, Hanford Downwinders Conference, Pendleton, WA, April, 1999.

Cancer and Three Mile Island, Three Mile Island Alert, Harrisburg, PA, March 26-27, 1999.

Environmental injustice in the North Carolina hog industry. Society of Toxicology Annual Meeting, New Orleans, LA, March 17, 1999.
Radiation and health, Livermore City Council, Lawrence Livermore National Laboratory, October 22-24, 1998.

Radiation and mortality among US Department of Energy workers: Relevance to radiation protection standards. NY Academy of Medicine, New York, September 26, 1998.

Health effects of Department of Energy Facilities. Physicians for Social Responsibility Annual Meeting, Arlington, VA, May 1, 1998.

Committee on Veterans Affairs, United States Senate, 105th Congress Second Session, "Ionizing Radiation, Veterans Health Care, and Related Issues," Washington, DC, April 21, 1998; published testimony: Serial HRG. 105-983, pages 14-16 and 111-113, U.S. Government Printing Office, Washington, DC.

Environmental justice in North Carolina, East Carolina University Brody School of Medicine, Greenville, NC, April 17, 1998.

Radiation epidemiology, Hanford Health Effects Subcommittee (CDC-ATSDR), Seattle, WA, 1997.

How communities affect epidemiology: A re-analysis of cancer incidence near Three Mile Island. Community Partnership Research Conference, Clark University, September 21, 1996.

How pure is the quantitative basis of epidemiology? An examination of four numerical concepts. London School of Hygiene and Tropical Medicine, July 1996.

Whose epidemiology, whose health? Department of Public Health, University of Liverpool, July 1996.

Department of Health and Human Services Advisory Committee on Energy-Related Epidemiologic Research, "Data collection and record access in epidemiological studies of workers at DOE facilities," Santa Fe, NM, April 18, 1996.

Occupational inequalities in mortality. Division of Occupational and Environmental Medicine, School of Medicine, Duke University, February 2, 1996.

Environmental epidemiology, Conference on Cancer and the Environment: Women's Action for Prevention, Shaw University, Raleigh, NC July 7, 1995.

An epidemiological triangle: Questions, answers and methods. Joint meeting of the Brazilian, Ibero-American and Latin American Congresses of Epidemiology, Salvador, Bahia, Brazil, April 24-28, 1995.

Radiation risks and mammography, Health and Today's Environment: A Symposium on Action for Cancer Prevention and Natural Health, Albuquerque, NM, October, 1994
Low-level radiation panel, Radiation Health Effects and Hanford: A Conference for Concerned Citizens and Health Care Providers, Spokane, WA, September, 1994

Health risks from ionizing radiation, Massachusetts Low-Level Radioactive Waste Management Board, Worcester, MA, November 3, 1993

Concepts in modern epidemiology: Population, risk, dose response and confounding. Workshop on Critical Theory in Epidemiology, Department of Preventive Medicine, Federal University of Bahia, Salvador, Brazil, June 14-18, 1993.

Recording of external radiation exposures at Oak Ridge National Laboratory: Implications for epidemiological studies. Workshop on the Epidemiologic Use of Nondetectable Values in Radiation Exposure Measurements. National Institute of Occupational Safety and Health, Cincinnati, OH, September 9 and 10, 1993.

Towards a post-Columbian science of disease causation. Indigenous Peoples Forum/Medical and Scientific Methods for Diagnosing Human and Environmental Effects from Nuclear Testing, Las Vegas, Nevada, October 2-4, 1992.

Subcommittee on Compensation, Pension and Insurance of the Committee on Veteran's Affairs, House of Representatives, 102nd Congress Second Session, "H.R. 3236 and H.R. 4458, Bills Affecting Veterans Exposed to Ionizing Radiation in Military Service," May 27, 1992. Published testimony: Serial No 102-42, pages 10-16 and 51-52, US Government Printing Office, Washington: 1992.

Recent findings on low-dose radiation and mortality at the Oak Ridge National Laboratory, U.S.A. Institute for Radiation Hygiene, Munich, Germany, March 5, 1992.

Recent findings on low-dose radiation and mortality at the Oak Ridge National Laboratory, U.S.A. German Cancer Institute, Heidelberg, Germany, March 4, 1992.

Recent findings on low-dose radiation and mortality at the Oak Ridge National Laboratory, U.S.A. Institute for Radiation Biology, University of Munster, Munster, Germany, March 3, 1992

Study of worker exposure at Oak Ridge National Laboratory. Low Level Radioactive Waste Forum Quarterly Meeting, New Orleans, LA, April 19, 1991.

Health effects of low level radiation, Chatham County, NC Low-Level Radioactive Waste Site Designation Review Committee, April, 1991

Health effects of low level radiation, Richmond County, NC Low-Level Radioactive Waste Site Designation Review Committee, April, 1991

Factors associated with the onset and magnitude of the decline of cardiovascular disease mortality in the United States. First International Searle Symposium on Prevention and Epidemiology, Ulm, Germany, July 5, 1990.

An epidemiological study of low dose occupational exposure to ionizing radiation. First International Searle Symposium on Prevention and Epidemiology, Ulm, Germany, July 5, 1990.

Social inequalities and health: The contradictory role of health professionals. 17th Annual Regional Conference on Maternal and Child Health, Family Planning, and Services for Children with Special Health Needs, Raleigh, N.C., May 2, 1990.

TEACHING

UNC Courses

2011-15 Lead instructor, Perspectives in Epidemiology and Public Health (EPID 890) (5 – 12 students per semester, fall and spring semesters)
A seminar for first-year MSPH students in the Department of Epidemiology.

2010 Lead instructor, Environmental Epidemiology (EPID 785) (14 students).

Introduction to topics and methods in environmental epidemiogogy.

2000- Lead instructor, Community-Driven Epidemiology and Environmental Justice (EPID 786) (7 – 15 students per semester)
Principles for conducting research within communities unduly burdened by environmental health threats. Topics include research ethics, community presentations, study design and implementation, and student research projects. EPID 278 was was selected as an innovative course by The Consortium for Environmental Education in Medicine in 2000, and was nominated by the Theta chapter of Delta Omega for the Delta Omega Award for Innovative Public Health Curriculum in 2001.

1997-99; 2007 Co-instructor, Occupational Epidemiology (EPID 276)

The course provides a background in the epidemiology of work-related illness and injury and the application of epidemiologic concepts and methods in protecting workers' health and safety.

1996- Lead instructor, History and Philosophy of Epidemiology (EPID 891) (12 – 28 students per semester)
This seminar exposes epidemiology doctoral students to issues and debates in the philosophy of science, the objects of knowledge in epidemiology, and the place of epidemiology in public health.

1994-97 Co-instructor, Advanced Methods in Epidemiology (EPID 268)
An in-depth treatment of key mehtodological topics in epidemiology, including concepts of cause, confounding, control selection, data quality, sampling variability, and effect modification.

1992-95 Instructor, Philosophy of Epidemiology (EPID 217)
A forum for evaluating the place of epidemiology in science, public health and society, focusing on the nature of objectivity and the social consturction of epidemiological knowledge.

1987-91 Instructor, co-instructor, Principles of Epidemiology (EPID 160)
An introductory course that considers the meaning, scope, and applications of epidemiology to public health practice and the uses of vital statistics data in the scientifi appraisal of community health.

1985-87 Co-instructor, Cardiovascular Disease Epidemiology (EPID 256)
Review of the main causes of cardiovascular disease morbidity and mortality, and their population determinants. Topics include epidemiologic methods, risk factors, strategies for prevention, and a student research project.

Other Courses

2011 Co-instructor, Cancer Epidemiology and Environmental Health Risk Assessment. University of Greifswald short course, Antalya, Turkey.

2007 Johns Hopkins University Fall Institute, Barcelona, Spain. Social Justice and the Environment (with Joan Benach).

1997 Co-instructor, Occupational and Environmental Epidemiology, Institute of Collective Health, Federal University of Bahia, Brazil. An introduction to epidemiology in occupational and environmental health.

1993 Lead instructor, Problems in Epidemiology: Methodology and Philosophy. Department of Preventive Medicine, Federal University of Bahia, Brazil.
An advanced seminar in philosophy of epidemiology conducted with faculty and students from UFBA.

1990 Co-instructor, Principles of Epidemiology, 4-week introductory graduate-level course. University of Ulm, Germany. An introductory course that considers the meaning, scope, and applications of epidemiology to public health practice and the uses of vital statistics data in the scientific appraisal of community health.

CONTRACTS & GRANTS

Submitted

Health and Air Pollution from Confined Animal Feeding Operations (principal investigator). National Institue of Environmental Health Sciences, R01, proposed 9/1/2014-8/31/2019.

Aromatic Amines and Bladder Cancer among Workers Exposed to Epoxy (co-investigator). National Institute for Occupational Safety and Health, R01.

Active

The impact of intensive livestock production on the disease ecology of antibiotic resistant staphylococcus (co-investigator). National Science Foundation, 2013-2016.

Air emissions from industrial animal operations and respiratory health of adolescents (principal investigator), Johns Hopkins University, 2009-2015.

Completed

2014 North Carolina Environmental Justice 2014 Summit Proposal (principal investigator), National Institue of Environmental Health Sciences, R13.

2013 Pathways for human uptake of emerging chemicals of concern in land-applied sewage sludge. Center for Environmental Health and Sustainability small grant (principal investigator), NIEHS.

2013 North Carolina Environmental Justice 2013 Summit Proposal (principal investigator), National Institue of Environmental Health Sciences, R13.

2009 Long-term Effects of Occupational Radiation Exposures (co-investigator), 2009-13.

2007 Community Health Effects of Sewage Sludge (principal investigator). National Institute of Environmental Health Sciences, 2007-2013.

2006 Epidemiologic Surveillance and Investigation of Symptoms of Illness Reported By Neighbors of Biosolids Land Application Sites (principal investigator), Water Environment Research Foundation, 7/1/2007-8/31/2008.

2003 Agricultural Dust and Childhood Asthma Symptoms (principal investigator, doctoral research of Maria Mirabelli), National Heart Lung and Blood Institute R01 HL073113, 04/01/03 – 03/31/05.

2002 Improving Environmental Health Research Through Dialogue (co-investigator). National Institute of Environmental Health Sciences, 9/30/02 - 8/31/07.

2002 Susceptibility in Occupational Radiation Risks (co-investigator). National Institute for Occupational Safety and Health, 9/30/02-9/29/05.

2002 Time-Factors in Exposure Effects Among Uranium Workers. (co-investigator). National Institute for Occupational Safety and Health, 5/01/02 - 4/30/05.

2002 Community-Driven Research on Environmental Justice and Landfills in North Carolina (principal investigator). Jesse Ball duPont Fund, 01/01/02 – 12/31/05.

2001 Community Health Effects of Industrial Hog Operations. (principal investigator). National Institute of Environmental Health Sciences, 09/01/01 - 08/30/08.

2000 Work and Health Disparities among Rural Women: Epidemiology Support (principal investigator). Duke University -- National Institute of Environmental Health Sciences, 09/30/00 - 09/29/05.

2000 Short Courses for Environmental Health Research Ethics: North Carolina Component (principal investigator). Syracuse University -- National Institute of Allergy and Infectious Disease, 09/30/00 - 08/31/06.

2000 Community Health and Environmental Reawakening (principal investigator). National Institute of Environmental Health Sciences, 09/01/00 - 04/30/09.

2000 Minority Graduate Research Assistant Supplement to Community Health and Environmental Reawakening (principal investigator). National Institute of Environmental Health Sciences, 09/01/00 - 08/30/01.

1999 Environmental and Public Health Impacts of Intensive Livestock Operations in the Wake of Flooding from Hurricane Floyd (principal investigator). Center for a Livable Future, Johns Hopkins School of Public Health, 01/01/00 - 12/30/00.

1998 Rural Health Study (principal investigator). North Carolina Department of Health and Human Services, 7/1/98 – 6/30/99.

1998 Older Women, Dietary Intake and Dependence on the Local Food Environment (principal investigator, doctoral research of Kimberly Morland, 07/01/98 – 06/30/99.

1997 Enabling Community-Based Environmental Research and Education (Principal Investigator). Chancellors Office, University of North Carolina at Chapel Hill, 12/01/97 - 6/30/98.

1997 Environmental Justice and Community-Based Prevention/Intervention Research Conference Grant, supplement to Southeast Halifax Environmental Reawakening (principal investigator). National Institute of Environmental Health Sciences, 09/01/97 - 08/31/99.

1996 Bahia-US Environmental Epidemiology Training and Research (co-investigator). Fogerty International Center, National Institutes of Health, 9/30/96 - 09/29/01.

1996 Ionizing Radiation and Mortality Among Hanford Workers (principal investigator). National Institute for Occupational Safety and Health, 09/30/96 - 09/29/01.

1996 Southeast Halifax Environmental Reawakening (principal investigator). National Institute of Environmental Health Sciences, 09/01/96 - 08/30/00.

1996 Critical Review of the United States Department of Energy Efforts to Investigate the Human Health Effects of Plutonium (principal investigator). Berger-Montague, 07/18/96 – 07/17/97.

1995 Time Related Factors in Radiation-Cancer Dose Response (principal investigator, Doctoral research of David Richardson). National Institute for Occupational Safety and Health, 07/01/95 - 06/30/97.

1994 Epidemiological Studies of the Accident at Three Mile Island (principal investigator). Center for Environmental Studies, John Snow Institute, 03/01/94 - 12/31/95.

1993 Study of Multiple Myeloma Among Workers Exposed to Ionizing Radiation and Other Physical and Chemical Agents (principal investigator). National Institute for Occupational Safety and Health, 10/01/93 - 02/29/96.

1992 Geographical Differentials in Stroke Mortality Levels and Trends in the U.S. (principal investigator). Centers for Disease Control, 08/28/92 - 03/30/93.

1992 The Potential Impact of Ill-Defined Mortality on the Decline of Ischemic Heart Disease in the U.S. (principal investigator, Doctoral research of Donna Armstrong). American Heart Association, North Carolina Affiliate, 07/01/92 - 06/30/93.

1990 Minority Graduate Research Assistant Supplement to Community Structure and Cardiovascular Mortality Trends (principal investigator). National Heart, Lung and Blood Institute, 07/01/90 through 05/31/92.

1989 Community Structure and Cardiovascular Mortality Trends (principal investigator). National Heart, Lung and Blood Institute, 06/01/89 - 05/31/93.

1987 Health and Mortality of Department of Energy Workers (co-investigator). U.S. Department of Energy, 10/01/87 - 03/31/94.

SERVICE

Department

Masters Examination Committee, Ad Hoc Core Course Review Committee, Masters Program Committee, Departmental Seminar Committee, Ad-hoc Task Group on Integration of the Core Methods Courses, Faculty Task Group on Course Evaluations, Curriculum Committee, Doctoral Qualifying Examination, Graduate Studies Committee, Awards Committee, MSPH Program Advisor

School

Greenburg Alumni Endowment Awards Committee, 2005
UNC Housekeeper Health Study Co-investigator, 1997-1999
Committee on Learning Environments and Research Networking for the 21st Century, 1995-1996
Institutional Review Board, 1994-1997
School of Public Health Awards Committee

University

Center for Health Promotion and Disease Prevention Population and Policy Working Group, 1998
University Faculty Council, 1993-1996
Buildings and Grounds Committee, 2009-2012

State

Member, Toluene Diisocyanate Advisory Panel, NC Division of Occupational and Environmental Epidemiology, 2007-2009.
Vice-President, NC Conference of the American Association of University Professors, 2007-2009.
North Carolina Central University, Advisory Board, Environmental Risk and Impact in Communities of Color and Economically Disadvantaged Communities, 2001-2002.
North Carolina Environmental Justice Network, member, annual NC Environmnetal Justice Summit Planning Committee, 1998 - present.
Center for Community Action, Lumberton, NC. Reviewer, health effects of tire pyrolysis facility, 1996.
Clean Water Fund of NC, Ashville, NC. Review of cancer studies in Paw Creek conducted by the NC Department of Health and Human Services, 1996.
Land Loss Fund, Tillery, NC, consultation on land loss and public health, National Black Land Loss Summit planning committee member, 1996.
UNC Alumni Heart Study (Duke University), research design consultation, 1985-88.

National

Institute of Medicine, Exploring the True Costs of Food: A Workshop, 2012
Agency for Toxic Substances and Disease Registry, peer reviewer, 2002.
Concerned Citizens for Nuclear Safety, Santa Fe, NM, 2000-2002.
California Environmental Protection Agency, member and Co-Chair, Santa Susanna Field Laboratory Advisory Panel, 2000-2002.
East Hampton Town Hodgkin's Cancer Task Force, East Hampton, NY. June 4-5, 2000.
US General Accounting Office, Denver, CO. Epidemiological evidence relevant to radiation protection, 2000.
West Virginia University, Morganton, WV. Social Environment and Rural Community Health Project, October 7-8, 1999.
National Academy of Sciences, Washington, DC. Reviewer, Review of the Hanford Thyroid Disease Study Draft Final Report, 1999.
Rural Coalition, Washington, DC. Presentation and consultation on community based evironmental health research, National Advisory Board, April 6, 1998.
Pan American Health Organization, Washington, DC. Review of literature on social inequalities in health (with David Richardson), 1998.
Ministry of Health and Environment, Schleswig-Holstein, Kiel, Germany. Review of literature on radiation health effects (with David Richardson and Alice Stewart), 1997-1998.
Clark University, Worcester, MA. Member of planning committee, Community Research Partnership Conference, 1996.
Yakama Indian Nation Environmental Restoration and Waste Management Program, Toppenish, WA. Consultation on radiation epidemiology, 1995.
Centers for Disease Control, Atlanta, GA. Reviewer of educational materials on health effects from the Hanford Plutonium prodcution facility, 1995.
American Public Health Association, Washington, DC. Member, Task Force on Social Welfare Policy, 1992-1993; co-author of Social Welfare Policy Statement.

Three Mile Island Public Health Fund Scientific Advisory Board, Philadelphia, PA. Consultation on radiation epidemiology, October, 1992.
Ministry of Health and Environment, Schleswig-Holstein, Kiel, Germany. Consultation with the Minsister of Health regarding radiation protection policy. March, 1992.
Northwest National Life Insurance Company State Health Rankings, Delphi Panel Member, 1992.

International

Scientific and Ethics Committee for the Clinical Study of the F1 Offspring of A-bomb Survivors

LEGAL RESEARCH AND TESTIMONY

United States District Court for the Southern District of West Virginia, OVEC et al. vs. FOLA Coal Company, LLC, 2015.
United States Environmental Protection Agency, Complaint Under Title VI of the Civil Rights Act of 1964, 42 U.S.C. § 2000d, 40 C.F.R. Part 7, 2014.
United States District Court for the Easter District of North Carolina, Multiple Plaintiffs vs. Murphy Brown, LLC, 2014.
United States District Court for the Western District of Pennsylvania, Alynda Talmadge, et al. vs. Babcock and Wilcox Power Generation Group, Inc., et al., 2014.
Wake County Superior Court, Waste Industries USA, Inc. and Black Bear Disposal, LLC vs. State of North Carolina and North Carolina Department of Environment & Natural Resources. 2010.
State of North Carolina Wake County Office of Administrative Hearings. Jerry Franks, Petitioner, vs. North Carolina Department of Environment & Natural Resources and Wake County Board of Commissioners, Respondents.
United States District Court for the District of Colorado, Merilyn Cook, et al. v. Rockwell International Company and the Dow Chemical Company, Civil Action No. 90cv00181JLK.
United States District Court for the Middle District of Pennsylvania. TMI Litigation Cases Consolidated II, Civil Action No. 1:CV-88-1452.
United States District Court for the Eastern District of Tennessee Northern Division at Knoxville. Euchee Marina & Campground, et al., Plaintiffs vs. Martin Marietta Energy Systems, Incorporated, et al., Civil Action No. 3-91-0510.
United States District Court for the Southern District of California. Glen and Doreth James, Plaintiffs, vs. Southern California Edison Company, et al., Case No. 94-1085 NJ (RBB).
District Court of Harris County, TX, 125th Judicial District. Terry Joe Groom, Plaintiff, vs. Schlumberger Technology Corporation et al., Case No. 94-42682.
United States District Court for the District of Colorado. Merilyn Cook, et al., Plaintiffs, vs. Rockwell International Corporation and The Dow Chemical Company, Civil Action No. 90-K-181.
Carolyn Mull, Personal Representative of the Estate of Roy Mull, Employee/Plaintiff vs. Duke Energy Corporation, Employer/Defendant, North Carolina Industrial Commission File No. 717904.

JOURNAL REVIEW

Accountability in Research: Policies and Quality Assurance
American Journal of Epidemiology
American Journal of Industrial Medicine
American Journal of Public Health
Annals of Epidemiology
CA - A Cancer Journal for Clinicians
Environmental Health
Environmental Health Perspectives
Environmental Research
Environmental Science: Processes and Impacts
Epidemiology
Epidemiology Research International
Health Education and Behavior
Journal of Epidemiology and Community Health
Journal of Exposure Science And Environmental Epidemiology
Journal of Gerontology
Medicine and Global Survival
New Solutions: A Journal of Environmental and Occupational Health Policy
Occupational and Environmental Medicine
Progress in Community Health Partnerships: Research, Education, and Action
Radiation Research
Science of the Total Environment
Social Movement Studies
Social Science and Medicine
New England Journal of Medicine
New Solutions

GRANT REVIEW

NIEHS special emphasis panel for Conference Grants (R13 Applications), April, 2014

NIEHS special emphasis panel, Environmental Justice: Partnerships for Communication, April, 2005.

NIEHS special emphasis panel, Environmental Health Sciences Center Grants, June, 2002.

NIEHS special emphasis panel, Community Based Prevention and Intervention Research, March 2000.

NIEHS special emphasis panel, Environmental Justice: Partnerships for Communication, February 1999.

NIEHS special emphasis panel, Community Based Prevention and Intervention Research, July 1996.

Alberta Cancer Board, 1992.

Exhibit 2 to the
Declaration of Professor Steven B. Wing, Ph.D.

3 Environmental Injustice Connects Local Food Environments with Global Food Production

Steve Wing

> President Dwight Eisenhower warned the nation about the dangers of the military-industrial complex—an unhealthy alliance between the defense industry, the Pentagon, and their friends on Capitol Hill. Now, the agro-industrial complex—an alliance of agriculture commodity groups, scientists at academic institutions who are paid by the industry, and their friends on Capitol Hill—is a concern in animal food production in the 21st century.
>
> **Robert P. Martin (2008)**

The concept of the local food environment focuses attention on the kinds of groceries and restaurants that are available in people's neighborhoods. It challenges the unrealistic (and potentially detrimental and discriminatory) notion that education about what to eat necessarily improves mass nutrition. Although people with means who live in neighborhoods with healthy foods can change what they eat based on nutrition education (including commercial advertising), many people live where healthy foods are simply not readily available or unaffordable. The concept of the local food environment is an extension of the basic principle of public health that the most effective means for promoting behaviors that prevent disease and promote health are those that create environments in which it is easier for people to make healthy, rather than unhealthy, choices (Milio 1976).

Variability in local food environments can be understood from several perspectives. Stores and restaurants locate where people buy their products. Culture and marketing affect food choices. Wealth and income determine what people can afford. Housing policies, immigration, and discrimination influence racial segregation of neighborhoods and placement of retail stores. Forces that promote exploitation and inequality versus equity affect the distribution of wealth. Agriculture, transportation, energy, and waste disposal affect relationships between urban and rural areas. Variations in local food environments are shaped in this ecological context.

Public health research has focused on social inequalities in local food environments in relation to race and class, and the consequences of that variability for diet and risk of disease (Morland et al. 2002a,b). Although clearly important for health disparities, this heterogeneity of local food environments occurs within an industrial uniformity that is imposed by consolidation and concentration throughout the food system, from agricultural production to product development, to distribution and marketing. For example, the U.S. Department of Agriculture (USDA) estimates that, as of 2012, over 90% of soybeans and over 70% of corn planted in the United States are genetically modified crops (USDA 2012). Herbicide-tolerant and insect-resistant crops developed and controlled by large corporations that also produce companion chemicals establish uniformity in production by replacing conventional seed stocks that farmers could save and plant from one season to the next. Genetically modified corn and soybean products dominate the food supply through their use in grains, oils, and as feed for livestock. This uniformity, created through government policies that promote corporate control of the food supply, is projected to some extent into all local food environments.

The co-occurrence of variability in local food environments with uniformity of the mass food supply has significant public health consequences. One is bifurcation of food consumption. People who are well informed about nutrition, place a high value on health, have sufficient resources, and live in areas with access, can obtain foods that are locally produced, organic, fresh, and unprocessed. They may even choose foods based on other values, such as avoiding exploitation of farm and food-processing workers, animal welfare, or impacts on the environment. However, economic inequalities—for example, the fact that the bottom 80% of U.S. households held 4.7% of nonhome wealth in 2010, whereas the top 1% held 42.1% (Domhoff 2012)—mean that only a small proportion of people can afford to eat in this way. Low-income families must depend on the industrial food supply dominated by highly processed, high-calorie foods that, although available in wealthier neighborhoods, need not dominate diets of the people with means who live in those neighborhoods.

Bifurcation of food consumption, which is connected to differences in local food environments and diet between neighborhoods based on class and race, reflects the fact that consumers pay less for industrially produced foods than for foods produced by small- and medium-sized farmers and distributors. Consumer prices for industrial foods are low relative to historical food prices and to the costs of nonindustrial foods, because corporate producers do not pay for the environmental damages caused by industrial food production. This is the second public health consequence of the uniformity of the mass food supply that occurs together with variability in local food environments—the environmental health impacts of industrialized food production.

ENVIRONMENTAL INJUSTICE AND INDUSTRIAL FOOD PRODUCTION

Environmental injustice occurs when populations benefit from practices that negatively impact the environment of others. Food production always has the potential to create environmental injustice by depleting water supplies and reducing water quality, topsoil and soil productivity, and ecological diversity in agricultural areas that provide food for people in nonagricultural areas. This potential has been vastly expanded with the industrialization of agriculture. Industrialization "refers to the organization of agriculture as an in line, quasi-manufacturing process wherein the energy and materials of production are treated as exogenous to the system of biological productivity, and the primary goal is maximum sustained yield of single commodity items" (Mancus 2007).

Industrialized agriculture requires large inputs of fossil fuels and chemicals, notably inorganic nitrogenous fertilizer. Pollution from the production and refinement of oil, gas, and other petrochemicals impacts nearby communities (Allen 2006) in order to create inputs required by industrial agriculture. Therefore, the burdens of environmental pollution borne by communities in fossil fuel production areas benefit industrial agribusiness by helping to keep profits high and prices of industrially produced foods low. In agricultural areas, heavy chemical inputs can contaminate groundwater with nitrates and pesticides, and can lead to nutrient runoff that promotes eutrophication of surface waters. Furthermore, industrialization of agriculture leads to spatial concentration of production, requiring large-scale transportation of products to remote locations of consumption, with the additional demands for fossil fuels. In turn, spatial concentration of production brings about long-range transport of crops, depleting soil nitrogen and increasing the need for inorganic nitrogenous fertilizers, which (along with mechanical cultivation and monoculture) degrades the plant–soil relationships that make biological fixation of nitrogen possible, increasing further requirements for inorganic nitrogenous fertilizers (Mancus 2007). Large transportation corridors for agricultural products lead to excess local air pollution from ports, rail terminals, road traffic, destruction of housing and community facilities, and reduction of walkability in communities (Hricko 2006, 2008).

Exploitation of labor is rampant in agriculture. Chemical exposures, inadequate housing, and lack of sanitation affect the mental and physical health of many farm workers and their families (Villarejo 2003), while acute and repetitive trauma injuries are hazards in processing plants (Lipscomb et al. 2005, 2006, 2007, 2008). Workers in industrial animal confinements are exposed to bioaerosols, ammonia, and hydrogen sulfide (Donham 1993), and they exchange bacteria and viruses with livestock (Gray et al. 2007; Price et al. 2007). In the United States, agriculture is exempted from labor laws that cover industrial workers.

Industrial agriculture generates environmental injustice by exposing agricultural communities, workers, and urban populations to chemical production and goods movement; these populations suffer dangerous jobs and pollution in the interests of corporate profits and low consumer prices. Ironically, wealthy people can afford to buy from small, more sustainable producers, minimizing their consumption of foods produced in ways that generate the most environmental injustice, whereas low-income people must depend on the mass food supply that is more affordable because the costs of production are not counted. Industrial farm animal production in general, and pork production in particular, illustrates how products that are common to most local food environments create environmental injustices and health damage through the food production system.

INDUSTRIAL FARM ANIMAL PRODUCTION

Until the middle of the twentieth century, most meat, eggs, and milk came from farms that were located not too far from populations that consumed their products. Nonindustrial livestock farms support a diversity of production including pasture and grains used to feed the livestock. Livestock waste is used to fertilize the pastures and grains that become the next year's feed, establishing a feedback loop between animal and plant growth. Free-range animals fertilize soils as they graze, reducing the need for storage of animal wastes.

My experience with nonindustrial farms began in the 1970s when I moved to a rural area of North Carolina. My neighbors raised feed grains, chickens, and hogs. They fed the grain to their hogs. In the fall, after grain harvest, they released the hogs from their pens to roam through the fields where they consumed the remaining grains and plant parts and rooted up the soil, turning it over and depositing their waste.

In 1995, I met Gary Grant, director of the Concerned Citizens of Tillery, a grassroots organization in an area of eastern North Carolina where industrialized hog production was rapidly expanding. Given my experiences with hog farming in my community, I was surprised when Gary told me that his community and others in eastern North Carolina were having serious problems with hog farm pollution, which threatened the aquifers that supplied their drinking water and the air they breathed. This was a different kind of hog production than what I knew about from my neighbors.

Industrial hogs never touch the ground. Hundreds to thousands of hogs are kept in long buildings referred to as confinements, not the barns that my neighbors called pig parlors. Feeding is automated, and large fans help exhaust waste gases and dusts from the buildings. Feces, urine, spilled feed, and residues of pesticides drop below slats and are flushed into open cesspools, euphemistically referred to as lagoons. Gary explained to me that the waste pits in his community were dug into the water tables where rural residents, who lacked connections to municipal water supplies, drew their well water. Industrial producers empty these waste pits by spraying the liquid on nearby fields. Although the lagoons have clay or plastic liners that slow movement of fecal waste into the water table, the spray fields have no barriers to keep the liquid waste from groundwater, and many have subsurface drains, originally installed to make swampy land arable, which act as conduits for hog waste to reach surface waters.

Figure 3.1 shows the three primary components of an industrial hog operation in North Carolina: the confinements, the waste lagoons, and the spray fields. Confinement buildings must be ventilated, which exhausts waste gases and dusts into the surrounding neighborhood. Air and water pollution also come from the open waste pits and spray fields (Figure 3.2). North Carolina hog operations house as many as 20,000 pigs each, producing more waste than a city of 60,000 people, but with no sewer treatment plant.

Tillery is mostly African-American. Gary Grant's organization, Concerned Citizens of Tillery, grew out of civil rights era struggles for political enfranchisement, education, and fair treatment from local, state, and government agencies

FIGURE 3.1 **(See color insert.)** Industrial hog operation confinements, waste lagoons, spray fields, and home in the upper right. (Courtesy of Donn Young Photography, DSC no. 9566, Chapel Hill, North Carolina, 2013.)

FIGURE 3.2 **(See color insert.)** Hog waste spray fields aerosolize particles that can drift downwind and soak fields with fecal waste that can run off into surface waters and impact upper aquifers of ground water. (Courtesy of Dove, R., www.doveimaging.com, New Bern, North Carolina, 2013.)

that had favored the white power structure and practiced gross discrimination against people of color (Wing et al. 1996). Concerned Citizens of Tillery, located in Halifax County, North Carolina, had watched as, in the early 1980s, neighboring Warren County was chosen as the site for a toxic waste landfill, giving rise to the term environmental racism and the movement for environmental justice. They viewed industrial hog production as another form of environmental racism and the exploitation of African-American communities. At a meeting in an African-American church near an industrial hog operation in a neighboring county, I heard residents describe respiratory problems, water contamination, and hog odor so strong that they had to keep their houses shut, and their children inside. On the church's meeting room wall they posted a county map with pins of different colors that showed how close hog operations were located to African-American schools and churches. Residents had approached government officials with this evidence of discrimination, but they were told that their observations were anecdotal, not evidence of a systematic problem.

As industrial hog operations expanded in North Carolina from the 1970s into the 1990s, small- and medium-sized producers were driven out of business (Figure 3.3) (Edwards and Ladd 2000). By 1998, when the state adopted a moratorium on new lagoons and spray fields after a hog producer applied for a permit to construct a hog operation near golf courses and country clubs, the state was home to almost 10 million hogs.

As the population of pigs exploded, the geographic distribution of production imploded, concentrating heavily in the eastern part of the state known as the Black Belt (Figure 3.4) (Furuseth 1997). This region of North Carolina, part of the southern coastal plain where agriculture before the Civil War was based on slave labor, is where the majority of rural African-Americans still reside. Figure 3.5 shows that the proportion of nonwhites in North Carolina census block groups mirrors the spatial distribution of industrial hog operations in Figure 3.4.

With funding through a community-driven research and education program created by the National Institute of Environmental Health Sciences following President Clinton's executive order on environmental justice, we analyzed race and poverty statistics for North Carolina census block groups in relation to the presence of industrial hog operations permitted by the state. The study documented the excess of hog operations in low-income communities of color and showed that there were

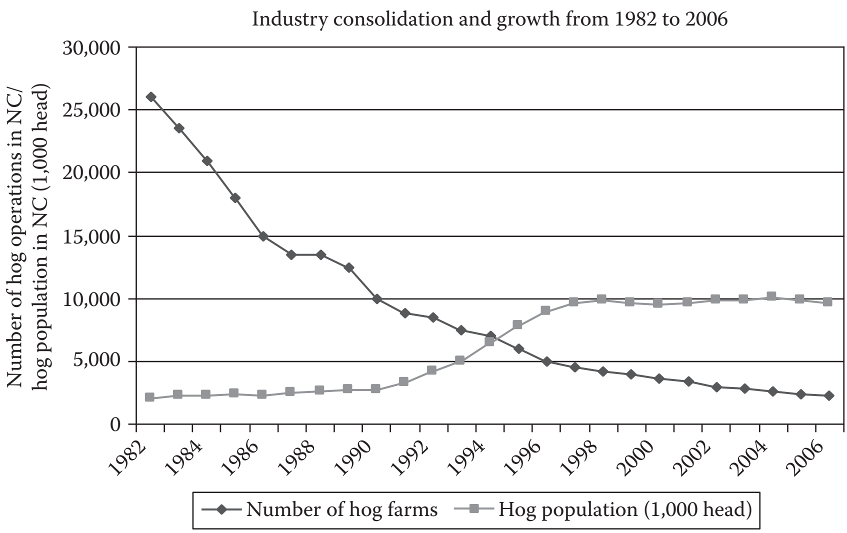

FIGURE 3.3 The North Carolina hog industry's consolidation and growth from 1982 to 2006. Growth is represented by the state hog population, whereas consolidation is exhibited in the number of hog farms in the state. (Edwards, B., *Twenty Lessons in Environmental Sociology*, 2009 by permission of Oxford University Press.)

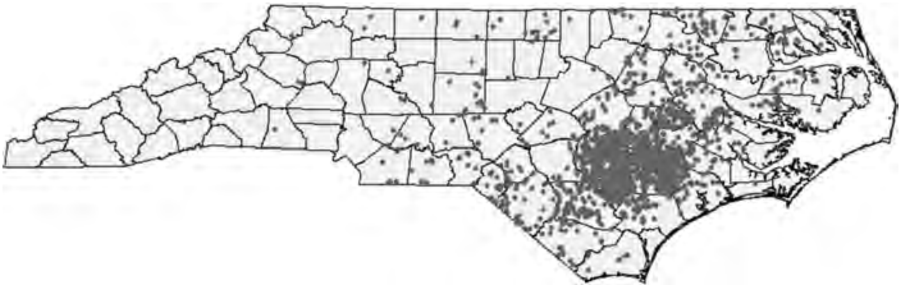

FIGURE 3.4 **(See color insert.)** The 2407 industrial hog operations permitted by the North Carolina Division of Water Quality. (From Wing, S. et al., *American Journal of Public Health*, 98, 1390–1397, 2008.)

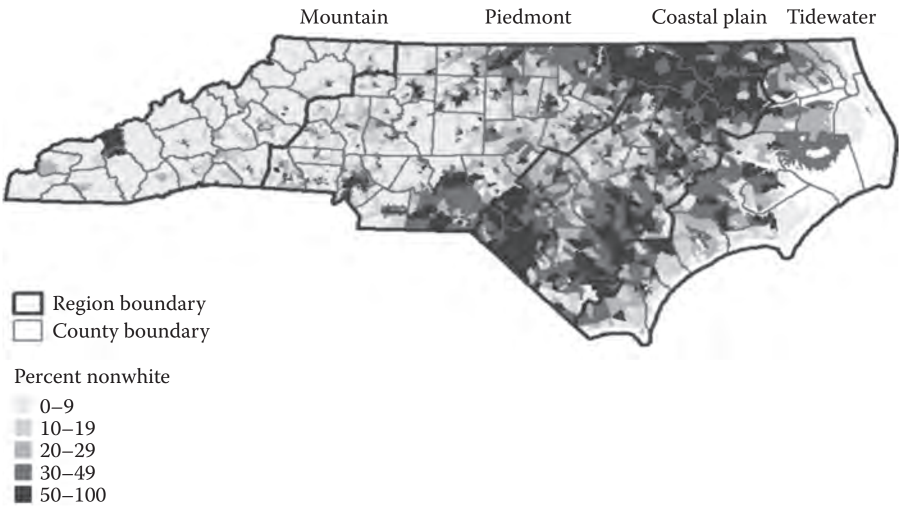

FIGURE 3.5 **(See color insert.)** Nonwhite percentage of the population of census block groups in North Carolina, 2010. (From Norton, J. et al., *Environmental Health Perspectives*, 115, 1344–1350, 2007.)

almost 10 times as many of these operations located in block groups with higher levels of poverty and people of color compared to the lowest levels, even after adjustment for how rural they are (Wing et al. 2000).

Health Effects of Industrial Hog Operations

Since the 1970s, researchers have documented the respiratory effects of working in hog confinements. In the 1990s, researchers began to publish results of studies of the mental and physical health of hog operation neighbors (Cole et al. 2000). A study of Iowa residents reported excess frequency of several clusters of symptoms among hog operation neighbors and was cited by eastern North Carolina residents as relevant to their health concerns (Thu et al. 1997). However, some officials said the Iowa study was not relevant to North Carolina. As Gary Grant responded, "They think hog shit smells different in North Carolina than in Iowa."

The Concerned Citizens of Tillery and other community-based organizations supported the idea of conducting similar research in eastern North Carolina. With funding and cooperation from the North Carolina Division of Occupational and Environmental Health and the National Institute of Environmental Health Sciences, we conducted a health survey of residents of three rural areas matched on demographic characteristics (Wing and Wolf 2000). Residents of one area lived within 3200 meter (m) of an industrial hog operation with about 6000 hogs and one lagoon, and in a second area within 3200 m of two adjacent dairy farms with a combined 300 cows and two lagoons. Residents of a third area lived more than 3200 m away from a livestock operation with a lagoon. Following an enumeration of households in each area, university researchers conducted a door-to-door survey of adults that included questions about physical symptoms and quality of life; the questions did not mention livestock or odor. The mostly white researchers were accompanied by members of African-American community organizations who introduced them to residents but were not present for the interviews. More than 90% of the 155 study participants were African-American and 65% were women.

Residents of the area with the hog operation reported more frequent respiratory and gastrointestinal symptoms, and reduced quality of life, compared to residents of the other areas, with adjustment for age, gender, smoking, and work outside the home (Wing and Wolf 2000). After results of the study were presented to community members at a meeting in Tillery, the North Carolina Department of Health and Human Services issued a press release announcing the results. Later that day, lawyers for the North Carolina Pork Council requested the identities of study participants, locations of their homes, responses to the questions we had asked, and copies of all documents produced in connection with the study. They also notified me and my coauthor Susanne Wolf that they were considering whether we had defamed the pork industry. Despite my obligation to keep the identity of research participants confidential, the University of North Carolina at Chapel Hill's response was to direct me to turn over all the documents. Only after I had obtained the assistance of a lawyer who would represent my interests and the interests of the study communities was I able to negotiate an arrangement to turn over documents that were redacted to protect the identity of the individuals and communities in the study. They did not pursue the charge of defamation.

This incident, which I wrote about in more detail in a 2002 article (Wing 2002), is relevant here because it indicates the clout of the pork industry in North Carolina and their willingness to use threat and intimidation against people who question their practices. The primary targets of these tactics are people who have fewest resources to combat them—community residents and workers. Industrial hog production not only exposes people to dusts, gases, bacteria and viruses but also exposes them to social and political infections that parasitize communities and whole societies. I expand on this later.

Results of the symptom survey were released in May, 1999. In September 1999, eastern North Carolina was hit by Hurricane Floyd. Subsequent flooding resulted in the release of massive quantities of hog waste into neighboring communities (Figure 3.6).

FIGURE 3.6 **(See color insert.)** Fecal waste pits flooded following Hurricane Floyd. (Courtesy of Dove, R., www.doveimaging.com, New Bern, North Carolina, 2013.)

FIGURE 3.7 **(See color insert.)** Tens of thousands of hogs drowned in the flooding from Hurricane Floyd. (Courtesy of Dove, R., www.doveimaging.com, New Bern, North Carolina, 2013.)

At least tens of thousands of hogs were drowned (Figure 3.7), resulting in serious carcass disposal problems.

We used digital satellite images from approximately 1 week after Floyd hit to estimate the number of hog operations that could have been affected, and found that the coordinates of 237 hog operations, permitted to house over 736,000 hogs, were within the flooded area (Wing et al. 2002). The North Carolina Division of Water Quality, which permits these facilities, reported that 45 hog operations were flooded, more than half of which were not classified as flooded in our analysis based on areas under water 1 week after the rains fell (Figure 3.8).

Although Hurricane Floyd resulted in an unusually large quantity of animal waste entering communities and surface waters of eastern North Carolina, tropical cyclones and locally heavy thunderstorms are routine occurrences in the state. Surveillance of environmental disease from these events, as in the case of routine releases, is hampered by lack of access to medical services.

We subsequently conducted a study of middle-school children who participated in a state-wide asthma survey in 1999–2000 (Mirabelli et al. 2006b). Schools' exposure to air pollutants from industrial hog operations were classified according to their distance to the nearest hog operation and also according to responses of school staff to a survey asking how often they noticed livestock odors inside school buildings. The prevalence of wheezing among 576 children attending three schools where school staff reported livestock odors inside more than two times per week was 23% higher than at schools where no livestock odor was reported, adjusted for 12 potentially confounding personal and environmental factors (Mirabelli et al. 2006b). Schools

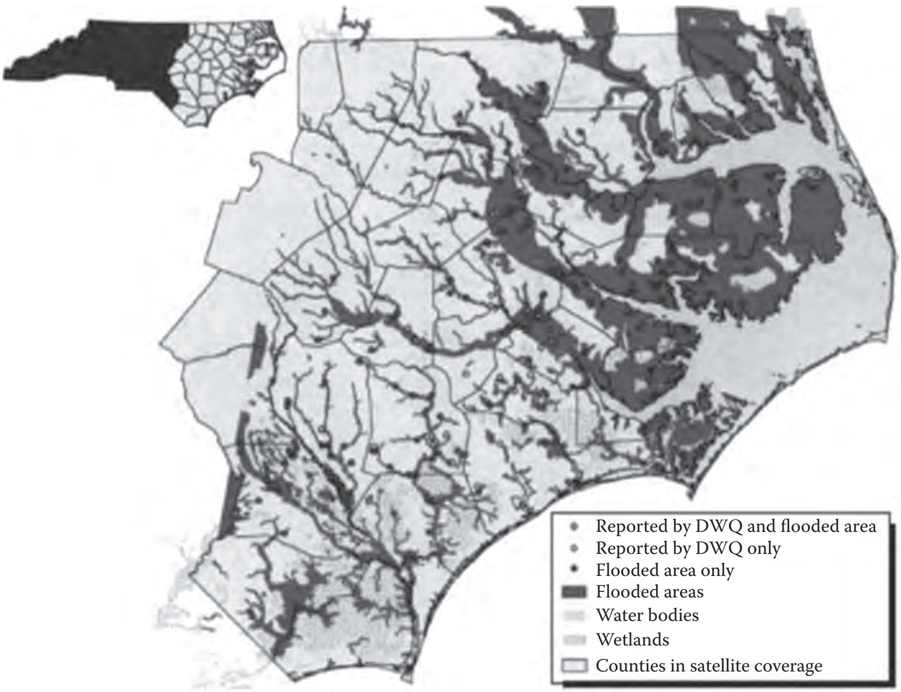

FIGURE 3.8 (See color insert.) Industrial animal production facilities with coordinates in the digital flood image or flooding reported by the North Carolina Division of Water Quality, September 1999. About 98% of these facilities were raising hogs. (From Wing, S. et al., *Environ. Health Perspect.*, 110, 387–391, 2002.)

with lower proportions of white children and more children receiving free and reduced lunch, an indicator of poverty, were closer to industrial hog operations—showing that environmental injustice extends to the educational environment (Mirabelli et al. 2006a). This North Carolina study is just one of a growing number of studies that find evidence of respiratory impacts of airborne emissions from industrial animal operations (Heederik et al. 2007).

These and other studies of the health of hog operation neighbors used information about exposure to pollutants (usually distance from the hog operation) and illness at the same time point. In such cross-sectional studies, it is not clear whether or not exposure occurs before the onset of illness. Distance is a crude measure of air pollution exposure. In addition, people who live near hog operations may differ in many ways, both known and unknown, from people who live in comparison areas, making it difficult to be certain that differences in illness are caused by hog pollution or something else. These limitations led us to conduct Community Health Effects of Industrial Hog Operations, a repeated-measures study of hog operation neighbors (Wing et al. 2008b). As in earlier studies, researchers partnered with the Concerned Citizens of Tillery to conduct the study. We also worked with a predominantly white community-based group, Alliance for a Responsible Swine Industry. Support from these groups was critical for the study because trust in government and research is low in areas impacted by industrial hog production.

Community organizers first talked with residents of neighborhoods near industrial hog operations and told them about the ongoing research (Wing et al. 2008b). They used maps from our prior environmental justice research to inform residents about the large number of hog operations in eastern North Carolina and their disproportionate placement in low-income communities of color. Many of these operations are located off main roads and behind stands of trees, so even local residents were not aware that so many of them were nearby.

People who expressed interest in participating in the study were asked if they would call the researchers or provide a phone number for the researchers to contact them. Nonsmokers aged 18 and above were invited to participate in the study for 2–3 weeks. They attended a training session where they provided consent to participate in research, their odor sensitivity was tested, and they learned to use the study instruments including a digital timer, an automated blood pressure monitor, a peak flow (lung function) meter, tubes for saliva collection, and a diary for reporting odors, health, and quality of life. Participants selected morning and evening times to sit outside on their porches every day for 2–3 weeks. While outside, they reported hourly levels of hog odor during the prior 12 hours in their diaries. Back inside, they recorded the level of hog odor that they noticed during the 10 minutes outside, physical symptoms, mood states including stress and anxiety, and daily activities. They measured their lung function and blood pressure using digital instruments that stored the data, and collected saliva in a tube that they stored in their freezer (Figure 3.9).

While participants collected data, we ran air pollution monitoring equipment on a trailer placed at a central location in the neighborhood (Figure 3.10). We monitored temperature, humidity, wind speed and direction, and hydrogen sulfide, a toxic gas produced by the decomposition of fecal waste that smells like rotten eggs. We also measured several components of particles less than 10 μ in diameter (PM_{10}): hourly

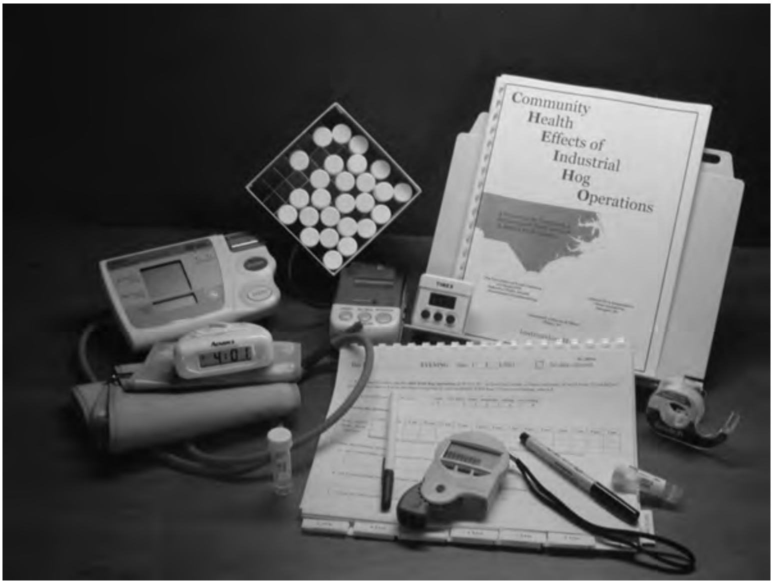

FIGURE 3.9 **(See color insert.)** Instruments used for data collection by participants in the Community Health Effects of Industrial Hog Operations Study. (Courtesy of Denzler, B., University of North Carolina.)

FIGURE 3.10 **(See color insert.)** Monitoring trailer used to house equipment for measuring hourly pollution levels in 16 neighborhoods in eastern North Carolina. (Courtesy of Denzler, B., University of North Carolina.)

PM_{10} and semi-volatile PM_{10}; 12-hour $PM_{2.5}$ (fine) and $PM_{2.5–10}$ (*coarse particles*); and endotoxin (Figure 3.10). The study was conducted sequentially in 16 communities where people lived within 2400 m of between 1 and 16 industrial hog operations (Wing et al. 2008b).

Rather than comparing hog operation neighbors to people who live somewhere else, we compared the health of hog operation neighbors during periods when they were exposed to pollutants from hog operations with their health during times when they were not exposed. Each person served as her or his own control, a design that controls for characteristics such as age, race, sex, medical history, and other factors that do not change during the short time of the study; however, this meant that we were not able to study chronic effects of exposure. Instruments for measuring air pollution and some outcomes were used, in part, to help avoid the potential for bias from self-reporting (Wing et al. 2008b).

Between 2003 and 2005, 102 volunteers completed the study protocol; one person who had trouble following the protocol was excluded from analyses. Among the remaining 101 participants who ranged in age from 19 to 89 years, 66 were women and 85 described themselves as black. They contributed 2949 records, typically two per day. Only two people dropped out before 14 days, and responses to individual diary questions were complete about 98% of the time (Schinasi et al. 2009). Blood pressure was missing in 1.4% of records; however, 34% of records had no valid lung function reading, reflecting the difficulty of performing that measurement (Schinasi et al. 2009).

Even though hydrogen sulfide concentrations were usually below typical odor detection threshold of 5–10 ppb, Figure 3.11 shows that the average hourly hog odor, reported on a nine-point scale from 0 (none) to 8 (very strong), varies in parallel with the hourly average hydrogen sulfide measured at the monitoring trailer (Wing et al. 2008a,b). Hog odor intensity during the 10-minute outdoor times rose, on average, 0.15 units per 1 ppb increase in measured hydrogen sulfide (Wing et al. 2008a). A similar relationship between hydrogen sulfide and odor was observed in a chamber experiment in which naïve volunteers were exposed to air from a hog confinement (Schiffman et al. 2005). Hog odor was related to PM_{10} only when the wind speed was above approximately 3 m/s; this may reflect the longer range transport of particles during higher wind conditions (Wing et al. 2008a). Participants reported disruptions of their daily activities far more often during periods of higher odor than lower odor (Wing et al. 2008a). Figure 3.11 also shows that average levels of hydrogen sulfide and reported hog odor were highest during morning and evening times when people are most often at home and wanting to engage in outdoor activities, especially during

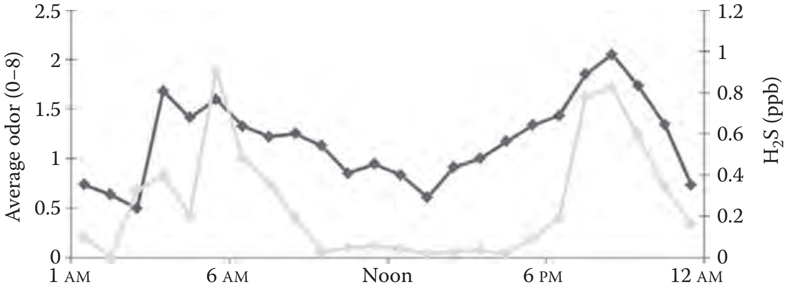

FIGURE 3.11 (See color insert.) Average hourly odor levels (left vertical axis) and hydrogen sulfide (right vertical axis) in 16 eastern North Carolina communities located near industrial hog operations. (Based on Wing, S. et al., *American Journal of Public Health*, 98, 1390–1397, 2008.)

the summer when mid-day temperatures are high. Participants reported hog odor during the 10 minutes outside on 61.3% of study days, and they reported hog odor inside their homes on 12.5% of days (Wing et al. 2008a).

Respiratory symptoms and mucous membrane irritation were also related to pollutant levels. The odds of reporting acute eye irritation immediately following the 10-minute outdoor exposure increased, on average, 16% for each 1 ppb increase in hydrogen sulfide and 43% for each 10 μg/m^3 increase in PM_{10} (Schinasi et al. 2011). The odds of reporting nasal irritation, burning eyes, difficulty breathing, and wheezing during the previous 12 hours increased 61%, 84%, 65%, and 132%, respectively, for a 10 μg/m^3 increase in $PM_{2.5}$. Endotoxin levels in the coarse particle fraction of PM_{10} were related to reports of chest tightness; however, semi-volatile and coarse particle mass was not related to respiratory symptoms or mucous membrane irritation (Schinasi et al. 2011).

Sensory exposures such as noise, threats, and pain can cause physiological changes and affect mental health. We asked participants to rate the extent to which they felt stressed or annoyed following their 10-minute times outside. The odds of feeling stressed or annoyed increased 18% for every 1 ppb increase in hydrogen sulfide concentration and 81% for each unit increase in hog odor on the 0- to 8-point scale (Horton et al. 2009). Systolic blood pressure, measured after returning indoors after the 10-minute outdoor exposure, rose an average of 0.29 mmHg for every 1 ppb increase in hydrogen sulfide, and diastolic blood pressure rose an average of 0.23 mmHg for a one unit increase in reported hog odor (Wing et al. 2013). The odor–diastolic blood pressure relationship is depicted in Figure 3.12, scaled to represent a participant whose average diastolic pressure was 80.5 mmHg during times of no odor.

After completing data collection in the repeated-measures study, qualitative researchers from our team conducted in-depth interviews with 49 of the participants using an interview guide designed to obtain detailed information about the context, beliefs, experiences, attitudes, and coping mechanisms of hog operation neighbors in relation to pollution from these facilities (Tajik et al. 2008). The interviews also

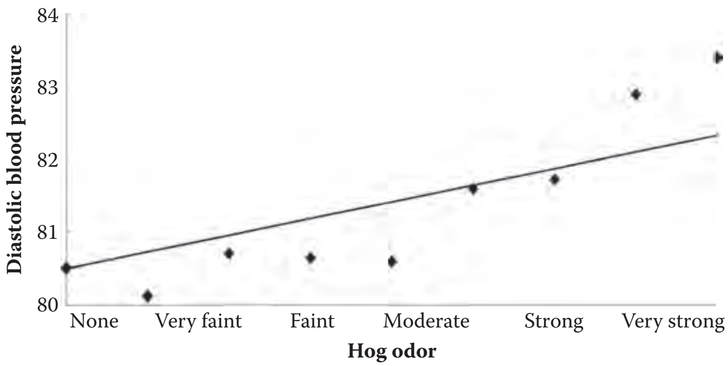

FIGURE 3.12 Average diastolic blood pressure at each level of reported odor, adjusted for time of day, and linear slope estimated by fixed effects regression, scaled to a person with an estimated blood pressure of 80.5 during times of no odor. (Based on Wing, S. et al., *Environmental Health Perspectives*, 121, 92–96, 2013.)

assessed individual and collective actions undertaken by community residents to resist the contamination of their neighborhoods. Each interview was conducted by a pair of interviewers: one academic and one community organizer. The participants were asked what they like and dislike about their community, what it was like growing up, how things had changed, how they responded to hog odor, and what they could do about the odor. Interviews were recorded and transcribed, and themes in the text were coded to identify common threads.

Tajik et al. (2008) summarized the impacts of hog odor in two primary areas that emerged from the interviews: (1) beneficial use of property and (2) quiet enjoyment of life. The theme beneficial use of property was based on statements about how low-income rural residents expect to be able to enjoy outdoor activities around their homes, such as walking, tending livestock, gardening, cooking out, and playing games. They also expect to be able to open their windows for fresh air and to be able to line-dry their clothes. Such activities are especially important for people who cannot afford or access fitness centers, vacation destinations, public facilities, or air conditioning (Tajik et al. 2008).

Participants said, for example, that hog odor prevented them from sitting outside, inviting guests for cookouts and family reunions, working and playing outside, drying clothes, and gardening. They talked about not being able to use their well water and having to buy bottled water. They talked about devaluation of their property and not being able to sleep at night because of the odor. In their own words:

> "A lot of my family come and can't stay here. They say, 'God, I can't stand this. How can you live here?'"
>
> "My son has asthma and allergies… he just stays inside."
>
> "I had a rose garden… do you see those weeds there… I haven't done it for the past few years…."
>
> "Sometimes it's so unbearable you couldn't even hardly stand it, not even in the house."
>
> "On a bad day it is not that you can't go outside… but the odor determines how long you gonna stay…"
>
> "When the smell [hog odor] get in, you can't get rid of it."
>
> "… I had stuff here in writing saying that the property has gone down 20–30 percent because you are near a hog farm."
>
> "The water turns everything yellow. If I wash my clothes for a good six weeks in that water, I will have to buy new clothes… I will have to buy new clothes every six weeks."
>
> "I don't drink the ground water no more because of the hog farms… now we have to buy water to drink."
>
> "It [hog odor] woke me up. And I had to get up. I couldn't sleep. I put the covers up over my face and it didn't do any good."

These interviews support findings from the repeated-measures study that hog odor affects people's ability to exercise outdoors, their sleep patterns, and their experience of stress and anxiety. Public health advocates tell people to exercise, get adequate sleep, and avoid social isolation. Neighbors of industrial hog operations report that hog odor interferes with following these basic health recommendations (Tajik et al. 2008).

Health Effects of Industrial Animal Production Extend Beyond Local Communities

Eastern North Carolina has the top 10 ranked counties for hog density in the United States. Three of these are the top ranked counties for turkey density. Broiler chicken production is also high in this same area. Although turkey and broiler operations do not use lagoons and spray fields, the confinements, manure storage sites, and spreading of manure on fields also produce air emissions that neighbors find to be offensive. Although industrial animal production has its most direct impacts on neighboring communities, the environment and health effects are not confined to local areas.

Historically, epidemic strains of influenza have emerged from interactions of people, pigs, and poultry in areas where humans are in close domestic contact with their animals. One argument for growing animals in confinement has been that this practice minimizes potential for infectious diseases to be transferred between people and livestock (Graham et al. 2008). However, a study of H1N1 swine flu in Iowa found that the odds of having H1N1 antibodies were 55 times higher in swine workers, and 28 times higher in their spouses, compared to people who did not live near livestock (Gray et al. 2007). Flu virus can be highly infectious and could spread rapidly from high livestock density areas to other populations. There has been concern that the 2010 global pandemic of swine flu originated in Vera Cruz, Mexico, an area of industrial swine production where the first case was identified.

The majority of antibiotics in the United States are used to promote livestock growth in confined growing facilities, not to treat human disease (Silbergeld et al. 2008). Such subtherapeutic administration contributes to the development of antibiotic resistance because bacteria that are susceptible to antibiotics produce fewer offspring than those with genetic resistance. In addition, resistance genes can be transferred directly between bacteria. Antibiotic resistance, which is traditionally identified with hospitals and human medicine, is an important public health problem because resistance makes treatment of human infection more difficult. Antibiotics commonly used to promote livestock growth belong to classes of drugs that are important in medicine; therefore, development of antibiotic resistance in livestock threatens to undermine treatment of human infection (Silbergeld et al. 2008). Several stains of methicillin-resistant *Staphylococcus aureus*, which is responsible for substantial morbidity and mortality, have been linked to livestock production (Smith and Pearson 2011). *S. aureus* sequence type 398 has been shown to be related to livestock density in the Netherlands (Feingold et al. 2012).

Industrial swine facilities typically use several measures to limit spread of pathogens. This is of economic importance due to the potential for animal mortality. Vehicles must have their tires disinfected upon entry, and workers must shower-in, shower-out, and change clothes when they leave confinement buildings. However, bacteria can survive in workers' nasal mucosa (Frana et al. 2013), and animal vectors such as rodents and birds, in addition to flies, can carry bacteria off-site (Graham et al. 2009). In one study, antibiotic-resistant bacteria were found in the feces of migratory geese that land on swine-waste lagoons (Cole et al. 2005). Bacteria resistant to antibiotics that are used in poultry feed have been found in excess behind poultry transport trucks and are carried by flies near poultry operations on Maryland's eastern shore (Rule et al. 2008).

Another animal feed additive of concern is arsenic, a human carcinogen. Arsenical drugs are common in poultry feed and may also be used in swine. Land application of animal wastes distributes arsenic onto land, potentially affecting ground and surface water, as well as food crops. Emphasis on renewable energy for electricity production, combined with the large excess of animal waste in high-density livestock production areas like eastern North Carolina, has led to pressures to burn poultry waste for electricity production, a practice that produces more air pollution than burning coal, which could result in widespread distribution of arsenic in the environment (Stingone and Wing 2011).

Traditional agriculture is based on producing a diversity of species. Because animal wastes are used to fertilize feed crops used to grow the next year's livestock, this system results in a feedback loop wherein wastes are recycled on the farm. Furthermore, in pasture-based operations, livestock play an important role in scavenging crop residues that remain in the fields after harvest, reducing insect populations, and conditioning soil by disturbing the ground and depositing manure. Diversity of production not only creates nutrient feedback loops and symbiotic relationships between multiple species but it also makes agriculture more resistant to periodic problems such as pests, drought, and temperature fluctuations, which usually affect one species more than others.

In contrast, industrial agriculture is designed to minimize diversity by focusing on a single crop (Mancus 2007). In the case of industrial animal production, feed is often produced at distant locations and transported to livestock-growing areas using fossil fuels. In the absence of manure fertilizer from livestock that consume feed grains, feed crops require more chemical fertilizers that require large fossil fuel inputs and increase levels of reactive nitrogen in the biosphere (Mancus 2007). Nitrogen pollution presents a myriad of health concerns due to respiratory impacts of air pollution, ingestion of nitrate-contaminated groundwater, and impacts on algal blooms and eutrophication of surface waters. Nitrogen pollution results not only from production of feed grains in the absence of animal manure but also from disposal of animal manure in the absence of adequate capacity for uptake by crops. Dense livestock-producing areas such as eastern North Carolina have large excesses of nitrogen and phosphorus from animal manures, which impact ground and surface waters in those locations and downstream coastal waters (Burkholder et al. 2007).

Livestock production is also an important source of methane, which is 25 times more potent than carbon dioxide as a greenhouse gas (Pew Commission on Industrial Food Animal Production 2008). Methane's half-life in the atmosphere is less than that of carbon dioxide, but it converts to carbon dioxide. Industrial livestock production's contribution to climate change shows that it affects environmental health over spatial scales from the local to the global.

ECONOMIC, SOCIAL, AND POLITICAL IMPACTS OF INDUSTRIAL ANIMAL PRODUCTION

Public health is affected not only by food quality but also by access to clean air and water, safe working and living conditions, quality education, medical and health services, and opportunities for physical activity. The extent to which these needs are met depends on the organization of social systems, the collective aspect of public health that determines individual exposures, choices, opportunities, and health inequalities. Industrialization of agriculture not only impacts environmental and occupational exposures in rural communities but also affects the political and food environments in both rural and urban communities.

Industrial animal agriculture is vertically integrated (Pew Commission on Industrial Food Animal Production 2008). This means that one company controls the production process from basic inputs to retail sale. Livestock producers either own animal production facilities or, more commonly, use contract growers, typically former family farmers, to raise the animals. In the case of hogs, the integrator owns the animals, animal feed, veterinary supplies, trucks, rendering plants, and processing plants. The contract grower owns (and has liability for) the buildings and the waste and must follow the integrator's terms for raising the animals. Most hog producers are unable to remain independent because they cannot get access to processing plants without a contract, and integrators control the processing plants (Pew Commission on Industrial Food Animal Production 2008).

Family farmers buy feed, equipment, and supplies from local retailers and spend their profits in their communities. In contrast, with industrial food animal production, corporations that integrate all aspects of production do not need to support local communities. In fact, corporations are legally responsible to maximize returns for their shareholders. Unlike businesses that support local communities, corporations syphon profits from rural communities for the benefit of distant shareholders. Their ability to impact rural communities is enhanced by campaign contributions and representation of business interests at all levels of government from local commissions and health boards to state legislatures, environmental agencies, and agriculture departments (Thu 2001). This political contamination, as detrimental to social and economic organization as toxins are to the health of individual humans, promotes economic inequalities and exploitation of workers while it prevents adoption of environmental and occupational protections that could be implemented to reduce impacts on rural communities. Perhaps most importantly, economic and political control of communities by national and global corporations prevents democratic participation and local control (Thu 2001, 2003).

The influence of corporate agribusiness at the state and national level inhibits the adoption of food safety regulations that could reduce the presence of pathogens, antibiotic-resistant bacteria, arsenic, and other contaminants in retail foods consumed by the general population. As in other areas such as pharmaceuticals, energy, and transportation, corporate influence helps direct government funds to university research that is more oriented toward industry profit than protection of the health of workers, residents exposed to pollutants, and consumers. Public land-grant universities are particularly harnessed in service to industrialized agriculture (Food and Water Watch 2012).

Industrialization of agriculture and the entire food system has promoted homogenization of food environments. Highly advertised packaged foods and chain restaurants result in the same foods being available in retail outlets across the country, and to some extent the world. Sugar, salt, fats, and flavorings, as well as appearance of foods and packaging, are manipulated to increase sales and consumption.

The convenience of packaged, prepared foods is not only attractive to people who work long hours in addition to caring for family members but makes it easier for everyone to eat more and more often. Resulting mass obesity, although it is often viewed as a problem of the obese person who lacks self-control, is an engine of profits, not only for food companies but for companies that sell clothes; exercise equipment and club memberships; diet pills; drugs for hypertension, hypercholesterolemia, and diabetes; and ultimately medical and surgical treatment of victims of ischemic heart disease, stroke, and other obesity-related conditions. Because changing the environment that promotes mass obesity will reduce industry profits, corporate control of the political system will need to be challenged if major changes are to occur.

Most pork, chicken, beef, dairy, and egg production occurs in concentrated animal feeding operations; for example, in 2007, 97% of hogs in the United States were housed in units with over 500 heads. This system is organized to produce profits for global corporations, and it results in cheap food because the environmental and human costs entailed by the system are not reflected in retail prices. Workers are sickened in factory farms and processing plants. Neighbors are exposed to air and water pollution that degrades their health, quality of life, and property values, and increases the cost of basic needs such as water and energy. Aquifers are contaminated, and surface waters suffer pollution that affects aquatic life and increases costs of water treatment in downstream communities. Retail meats are contaminated with antibiotic-resistant bacteria. These costs of industrial agriculture are not reflected in the price of food, which is in this way subsidized by loss of human and environmental health. Health disparities are fueled by the relatively higher dependence on these foods of low-income people compared to wealthier people.

How has this happened? The system is highly complex, but one feature has been key: environmental and social injustice. If workers and residents in rural communities that are most directly impacted had basic political and human rights, industrial agriculture would not have developed with such destructive force because those affected by its side effects would have been able to protect themselves. However, racism, classism, and political disenfranchisement of rural communities make it possible for the entire population to suffer detrimental health effects.

Addressing these problems will require many different strategies and struggles. Some may be taken by public health authorities acting as social engineers who, upon identifying pathological aspects of our food system, intervene to improve matters. Government interventions including environmental regulations, occupational safety and health rules, prohibitions on misuse of antibiotics and agricultural chemicals, and food safety regulations, are important. However, more fundamental changes in public health have been brought about not just by benevolent managers, but by mass movements such as the anti-slavery, women's rights, civil rights, peace, environmental, and human rights movements (Wing 2005). Such movements provide people who are most negatively impacted by exploitation with opportunities for self-preservation and increased protections, and in doing so improve conditions for the general population. Transformation of the food system, which can improve local food environments for all, depends on such basic social changes.

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Exhibit 3 to the
Declaration of Professor Steven B. Wing, Ph.D.

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Exhibit 4 to the
Declaration of Professor Steven B. Wing, Ph.D.

Intensive Livestock Operations, Health, and Quality of Life among Eastern North Carolina Residents

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People who live near industrial swine operations have reported decreased health and quality of life. To investigate these issues, we surveyed residents of three rural communities, one in the vicinity of an approximately 6,000-head hog operation, one in the vicinity of two intensive cattle operations, and a third rural agricultural area without livestock operations that use liquid waste management systems. Trained interviewers obtained information about health symptoms and reduced quality of life during the previous 6 months. We completed 155 interviews, with a refusal rate of 14%. Community differences in the mean number of episodes were compared with adjustment for age, sex, smoking, and employment status. The average number of episodes of many symptoms was similar in the three communities; however, certain respiratory and gastrointestinal problems and mucous membrane irritation were elevated among residents in the vicinity of the hog operation. Residents in the vicinity of the hog operation reported increased occurrences of headaches, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes as compared to residents of the community with no intensive livestock operations. Quality of life, as indicated by the number of times residents could not open their windows or go outside even in nice weather, was similar in the control and the community in the vicinity of the cattle operation but greatly reduced among residents near the hog operation. Respiratory and mucous membrane effects were consistent with the results of studies of occupational exposures among swine confinement-house workers and previous findings for neighbors of intensive swine operations. Long-term physical and mental health impacts could not be investigated in this study. *Key words:* African Americans, agricultural health, air pollution, epidemiology, respiratory conditions, rural health. *Environ Health Perspect* 108:233–238 (2000). [Online 8 February 2000]
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Industrial hog production has grown rapidly in North Carolina since the early 1980s. Once characterized by relatively small independently owned farms scattered across the state, hog production in North Carolina is now concentrated in the coastal plain region, under the domain of large corporate growers, and dominated by large-scale intensive operations (*1,2*). Persons who live near large hog operations have reported reduced quality of life as well as health problems related to airborne emissions from animal confinement houses, open waste lagoons, and spray fields (*3–8*). Airborne emissions include hydrogen sulfide, ammonia, dusts, endotoxins, and complex mixtures of volatile organic compounds. Health effects from environmental exposures could occur through inflammatory, immunologic, irritant, neurochemical, and psychophysiologic mechanisms (*5*).

In contrast to the many studies of occupational exposures of swine confinement-house workers (*9–25*), only a few field studies have investigated the health effects of lower level environmental exposures. In a study of residents near hog facilities in North Carolina, Schiffman et al. (*26*) reported that persons exposed to odors from intensive hog operations experienced "more tension, more depression, more anger, more fatigue, and more confusion" than a group of unexposed persons. A study in Iowa (*7*) compared physical and mental health symptoms among people residing within a 2-mile radius of a 4,000-head swine operation and a control group in an area with no intensive livestock operation. Those who lived in the vicinity of the intensive hog operation reported higher frequencies of 14 of 18 physical health symptoms, especially respiratory symptoms. The Iowa study did not find an excess of mental health symptoms but, in contrast to the North Carolina study (*26*), it was not designed to evaluate symptoms at the time that odors were present.

The present study addressed a number of issues raised by previous research. Unlike studies of volunteers, the sample was drawn systematically from defined populations. To increase the levels of participation and prevent exclusions based on literacy or the ability to participate in a longer study, we did not ask participants to keep a diary or respond to questions at the times that airborne emissions from livestock operations were noticeable. Instead, we asked questions about the number of times that participants experienced the symptoms of interest during the previous 6 months. Because mood disturbance and mental health effects may be acute responses to the presence of odors, we focused on physical health and quality of life rather than on short-term mood changes. We achieved high levels of participation in the study by establishing cooperative relationships with local community based organizations in planning and conducting the research.

This study compared health symptoms in residents of three North Carolina communities, one in the vicinity of an intensive hog operation, one in the vicinity of two intensive cattle operations, and a third in a rural agricultural area where no livestock operations used liquid waste management systems. Although the primary motivation for the study came from an interest in airborne emissions from swine operations, the inclusion of people residing near cattle operations afforded an opportunity to examine possible health effects from a different kind of livestock, and also offered a second comparison community that may share other features common to communities with intensive livestock production.

Materials and Methods

Selection of communities. The North Carolina Division of Water Quality (Raleigh, NC) maintains a database on intensive livestock operations that use liquid waste management systems (*27*). Information on livestock operations included in the database as of January 1998 was merged with 1990 U.S. Census block group data (U.S. Census Bureau, Suitland, MD). Data for block groups, which average approximately 500 households, included information on population size, race, and poverty levels. Maps of the eastern part of North Carolina

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were prepared showing the locations of livestock operations, towns, roads, and churches. Community consultants experienced with the hog industry and the health concerns of community members met with university researchers to review the maps and choose potential study sites. Our goal was to choose three areas with similar economic and demographic characteristics where residents would be willing to participate in an interview and where existing community based organizations would be interested in working with researchers. We sought livestock areas with 80–100 households within a 2-mile radius of the livestock facility so that we would be able to obtain approximately 50 participants in each area.

The hog and cattle study areas were defined by a < 2-mile radius around the operations and each study area was contained within a single census block group. The hog operation was a feeder-to-finish facility with a head capacity of approximately 6,000, a steady-state live weight of approximately 800,000 pounds, and one lagoon. The cattle community contained two neighboring dairy operations with a combined head capacity of approximately 300, live weight of approximately 200,000 pounds, and two lagoons. The area with no intensive livestock operations extended across two block groups. Parts of two block groups were included to ensure that eligible households were at least 2 miles away from any livestock operation using a liquid waste management system. The median annual family income of the census block groups from which the study areas were chosen ranged from approximately $17,000–23,000 and the populations were between 65 and 90% African American.

All habitable dwellings in the study areas were enumerated. The location of each dwelling was noted on an enlarged area map and was assigned a unique study number. Information on street or road location and the type of dwelling was entered into a computerized database.

Questionnaire. A structured questionnaire was developed based on previous research findings and on discussions with community members who had experienced exposures from intensive livestock operations. In addition to symptoms identified by previous studies or community residents as possibly related to airborne emissions from livestock operations, we included symptoms that we did not believe would be related to airborne emissions to evaluate the possibility that residents of exposed communities might report excesses of all types of symptoms because of negative feelings about intensive livestock operations. The questionnaire was designed to obtain information about the frequency of occurrence of each symptom over the 6 months preceding the interview. Possible responses were never; rarely (once or twice over the past 6 months); sometimes (1–3 times per month); often (1 per week); and very often (twice a week or more over the past 6 months). After all of the structured questions had been asked, respondents were asked about aspects of the environment that may have affected their own health or the health of others in the household. Interviewers took notes to summarize the types of responses. At the end of the interview, participants were asked their age, occupation, household size, source of drinking water, and whether they or others in the household smoked tobacco. The interviewers recorded race, sex, and whether anyone other than the participant and interviewer were present during the interview.

Household interviews. Adults 18 years of age or older with no serious speech or mental impairment who lived in the current residence for 6 months or longer were eligible to respond to the questionnaire. The households of dairy operators who lived beside the cattle facility were excluded to avoid the complication of occupational exposures; the household of the swine facility operator was not within the 2-mile enumeration area of the facility. Interviews were conducted on Fridays and Saturdays in January and February 1999 by university-based staff. Interviewers were accompanied by a community consultant, a local resident recruited from the membership of the community based organization. The community consultant introduced the interviewer to the prospective respondent, explained the purpose and importance of the survey, and encouraged each person to participate. Interviewers were trained to administer the survey instrument systematically and uniformly to all respondents. The participant interview was conducted in a location of the participant's choosing. The questionnaire required less than 15 min to complete. The community consultant was not present for the interview unless the participant specifically asked the consultant to remain.

One adult from each household was invited to participate in the survey. Preference was given to the first person to answer the door if

Table 1. Characteristics of study households, listed by type of livestock operation.

	Livestock operation			
Characteristic	None	Cattle	Hogs	Total
Inhabited houses	104	116	92	312
Households ineligible[a]	5	2	3	10
Not home	29	44	19	92
Rescheduled or not contacted	5	14	10	29
Completed interviews	50	50	55	155
Refused	15	6	5	26
Refusal rate[b]	23.1%	10.7%	8.3%	14.4%

[a]Not living in the house for 6 months; difficulty understanding survey questions. [b]Refusal rate = completed interviews/completed interviews + refusals.

Table 2. Characteristics of respondents.

	Livestock operation, no. (%)			
Characteristic	None	Cattle	Hogs	Total
Age				
19–44 years	19 (38)	13 (26)	23 (42)	55 (36)
45–64 years	19 (38)	19 (38)	20 (36)	58 (37)
65–90 years	12 (24)	18 (36)	12 (22)	42 (27)
Race/ethnicity				
African American	45 (90)	49 (98)	48 (87)	142 (92)
White	5 (10)	1 (2)	6 (11)	12 (8)
Latino	0 (0)	0 (0)	1 (2)	1 (1)
Sex				
Female	31 (62)	33 (66)	36 (65)	100 (65)
Male	19 (38)	17 (34)	19 (35)	55 (35)
Smoking				
Yes	14 (28)	13 (26)	7 (13)	34 (22)
No	36 (72)	37 (74)	48 (87)	121 (78)
Employed outside of the home				
Yes	26 (52)	15 (30)	34 (62)	75 (48)
No	24 (48)	34 (68)	21 (38)	79 (51)
Not completed	0 (0)	1 (2)	0 (0)	1 (1)
Number in household				
1	12 (24)	8 (16)	3 (5)	23 (15)
2	21 (42)	21 (42)	20 (37)	62 (40)
3–4	12 (24)	15 (30)	15 (27)	42 (27)
5–12	5 (10)	6 (12)	17 (31)	28 (18)
Total respondents (*n*)	50 (100)	50 (100)	55 (100)	155 (100)

the person was over 18 years old and lived in the household. Those who declined to participate because the time was inconvenient were offered alternative times and the visit was rescheduled. If no one was at home, the information was recorded on the tracking form. These households were visited a second time. Households were visited sequentially using the enumeration map in approximate order of distance from the intensive livestock operation until a minimum sample size of 50 was reached. Informed consent was requested verbally by the trained interviewer.

Statistical methods. Differences in symptoms among the three communities were evaluated by comparing the average number of episodes experienced over the last 6 months for each symptom. The number of episodes over the 6 months preceding the interview was scored according to the instructions given to respondents for responding to the frequency of symptoms. A response of "never" corresponded to 0 episodes. A response of "occasionally" corresponded to two episodes. "Sometimes" corresponded to 12 episodes (2/month), "often" corresponded to 26 episodes (1/week), and "very often" corresponded to 52 episodes (2/week). Adjusted mean differences in the numbers of episodes were calculated using linear regression to control for sex, age (19–44, 45–64, or 65–90 years), respondent's smoking status (yes or no), and employment outside the home (yes or no). These variables were considered potential confounders because they may be associated with exposure to airborne emissions and experience or reporting of symptoms. Because the five response categories for the number of episodes were highly skewed, regression models were also run with the dependent variable coded as the square root of the number of episodes and as 0–4.

The ratio of the β-coefficient (adjusted mean difference in number of episodes) to its SE yields a *t*-value. Larger absolute values of *t* indicate that the livestock variable is more important for statistically predicting numbers of symptom episodes. Significance tests are not presented because exposures were not randomized in this observational study; however, *t*-values > 1.66 would produce a significant one-tailed test of the hypothesis that average numbers of symptoms are greater in the livestock than in the control community at $p < 0.05$. Values > 1.98 would produce a significant two-tailed test at $p < 0.05$.

Results

Table 1 shows the numbers of households enumerated and surveyed. Enumerated households were within 2 miles of an intensive livestock operation in the cattle and hog communities. In the control area, enumerated households were > 2 miles from an intensive livestock operation in the control area. Approximately 100 households were enumerated in each area. Fifty interviews were completed in the cattle and control communities, and 55 interviews were completed in the hog community. The refusal rate was 23.1% in the control community, 10.7% in the cattle community, and 8.3% in the hog community.

Characteristics of the respondents are shown in Table 2. The cattle community had the largest proportion of respondents older than 65 years of age. All three communities were predominantly African American. Approximately two-thirds of the participants were female. The proportion of respondents who reported smoking tobacco was lower in the hog community than in the other two communities, whereas the proportion employed outside of the home was higher. None of the study participants reported that they worked in the livestock industry. Household size was largest in the hog community.

Responses to the symptom questions in the three communities are shown in Table 3. The symptoms were categorized in six groups: upper respiratory and sinus, lower respiratory, gastrointestinal, skin and eye irritation, miscellaneous, and quality of life. For each community we tallied the number of persons who answered "sometimes," "often," or "very often" corresponding to ≥ 12 episodes during the 6-month period. Table 3 also shows the percentage of "sometimes" or more often and the average number of episodes for the 6 months.

Most of the percentages in Table 3 are < 50; the majority of participants responded "never" or "occasionally" to most of the symptom questions. Among the upper respiratory and sinus conditions, the percentage of respondents reporting ≥ 12 episodes was the largest in the hog community except for

Table 3. Number and percent of respondents reporting 12 or more episodes, and mean number of episodes.

	Livestock operation					
	None		Cattle		Hogs	
Symptom	No. (%)[a]	Mean[b]	No. (%)[a]	Mean[b]	No. (%)[a]	Mean[b]
Total respondents	50 (100.0)	–	50 (100.0)	–	55 (100.0)	–
Upper respiratory/sinus						
Headache	16 (32.0)	7.8	18 (36.0)	9.4	34 (61.8)	15.5
Stuffy nose/sinuses	14 (28.0)	7.2	17 (34.0)	8.8	24 (44.4)	10.2
Runny nose	8 (16.0)	3.9	10 (20.0)	5.4	16 (29.1)	8.5
Burning nose/sinuses	11 (22.0)	4.1	9 (18.0)	3.4	14 (25.5)	6.7
Sore throat	2 (4.0)	0.9	6 (12.0)	2.5	9 (16.4)	4.7
Plugged/popping ears	10 (20.0)	5.5	11 (22.0)	5.2	11 (20.0)	4.6
Scratchy throat	6 (12.0)	2.2	10 (20.4)	3.8	10 (18.2)	4.4
Lower respiratory						
Mucus/phlegm	14 (28.0)	5.9	14 (28.6)	7.2	16 (29.1)	8.5
Excessive coughing	5 (10.0)	1.8	6 (12.0)	3.7	12 (21.8)	6.3
Shortness of breath	12 (24.0)	7.0	13 (26.0)	6.1	11 (20.0)	5.5
Tightness in chest	6 (12.0)	3.0	9 (18.0)	4.9	11 (20.0)	3.9
Wheezing	8 (16.0)	4.4	7 (14.0)	3.7	9 (16.4)	3.6
Strange breathing sounds	10 (20.0)	5.2	5 (10.2)	3.0	6 (10.9)	2.3
Gastrointestinal						
Heartburn	10 (20.4)	5.2	10 (20.0)	8.1	17 (30.9)	7.1
Nausea/vomiting	7 (14.0)	3.0	7 (14.0)	4.8	15 (27.3)	5.9
No appetite	8 (16.0)	2.8	8 (16.3)	4.1	12 (21.8)	5.5
Diarrhea	2 (4.0)	1.7	4 (8.2)	1.3	10 (18.2)	4.3
Skin/eye irritation						
Burning eyes	8 (16.0)	3.8	5 (10.0)	3.4	19 (35.2)	9.4
Tearing eyes	16 (32.0)	9.5	14 (28.0)	8.7	20 (36.4)	9.3
Dry/scaly skin	10 (20.0)	4.4	11 (22.0)	7.1	12 (21.8)	7.1
Skin rash or irritation	4 (8.0)	1.6	4 (8.0)	2.0	8 (14.6)	4.0
Skin redness	1 (2.0)	1.2	0 (0.0)	0.1	4 (7.3)	1.3
Miscellaneous						
Joint/muscle pain	24 (48.0)	16.1	26 (52.0)	17.2	28 (50.9)	16.7
Unexplainably tired	19 (38.0)	12.8	19 (38.0)	10.5	23 (41.8)	13.7
Blurred vision	15 (30.0)	8.8	9 (18.0)	5.4	16 (29.6)	9.7
Dizzy/faint	11 (22.0)	5.5	10 (20.0)	5.3	12 (21.8)	4.1
Hearing problems	7 (14.0)	7.4	5 (10.0)	2.0	6 (10.9)	2.7
Chest pain	10 (20.0)	3.4	6 (12.0)	1.6	6 (10.9)	2.7
Fever/chills	5 (10.0)	2.3	2 (4.0)	1.2	5 (9.3)	1.9
Fainted	0 (0.0)	0.04	0 (0.0)	0.04	1 (1.9)	1.0
Quality of life						
Can't open windows	7 (14.3)	3.2	4 (8.2)	1.8	31 (57.4)	18.5
Can't go outside	5 (10.0)	2.1	3 (6.0)	1.2	30 (55.6)	15.4

[a]Number and percentage of respondents answering sometimes (1–3 times/month), often (1/week), and very often (≥ 2 times/week over the past 6 months). [b]Average number of episodes per person over 6 months.

plugged ears and scratchy throats. Percentages were generally intermediate in the cattle community. The percentage of respondents reporting ≥ 12 episodes was generally smaller for lower respiratory, gastrointestinal, and skin or eye irritation symptoms. Percentages were the highest in the hog community for all four gastrointestinal symptoms. In all three communities, more than one-third of the participants reported experiencing joint or muscle pain and unexplained tiredness ≥ 12 times. By far the biggest differences between the communities were seen in the quality-of-life questions. Over half of the respondents in the hog community, as compared to less than one-fifth in the other two communities, reported not being able to open windows or go outside, even in nice weather, ≥ 12 times over the last 6 months.

Table 4 presents the results of the linear regression showing differences between the average number of episodes in each livestock community as compared to the community with no intensive livestock. Table 4 shows the difference in the mean number of episodes adjusted for sex, age, smoking, and work outside the home; the SE of the β-coefficient; and the *t*-value, which is the ratio of the β-coefficient to its SE (see "Statistical Methods"). The adjusted mean differences for the cattle community were generally small, with lower mean scores (negative β-coefficients and *t*-values) for many symptoms in the cattle as compared to the control community. Only episodes of excessive coughing and heartburn occurred on average > 2 times more in the cattle than in the control community (β > 2), and the *t*-values for these differences were only approximately 1.0. All of the symptoms in the miscellaneous category appeared less frequently in the cattle than in the control community. Hearing problems showed the largest difference in adjusted mean episodes, although this is based on a small number of people in the higher categories (Table 3).

In contrast, there were many mean differences of more than two episodes for the hog as compared to the control community. The average number of episodes was the most consistently elevated for upper respiratory and sinus conditions, gastrointestinal conditions, and skin or eye irritation. *t*-Values for headache, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes showed that residence in the hog community was an important predictor of these physical health symptoms. In contrast, none of the miscellaneous symptoms showed important excesses in the hog community.

Responses to the quality-of-life questions were very different in the control and cattle communities as compared to the hog community. The adjusted number of episodes during which participants could not open windows or go outside even in nice weather differed little for the cattle and control communities, whereas excesses of approximately 13–15 episodes were seen in the hog as compared to the control communities. *t*-Values for these β-coefficients were large.

To evaluate the sensitivity of the regression results to the coding of the dependent variable, the models shown in Table 4 were rerun using values of the square root of the number of episodes and as 0, 1, 2, 3, and 4. *t*-Values for differences between the hog community and the control community were larger in these models. The *t*-value for nausea/vomiting was 1.61 with the original metric, 2.68 using the square root of the number of episodes, and 2.88 with a coding of 0–4. To consider whether elevated gastrointestinal symptoms in the hog community might be related to well contamination, the models shown in Table 4 were rerun for the four gastrointestinal symptoms including a variable for well versus municipal water supply. The coefficients for well water were small and had little influence on the estimates of differences between livestock and control communities.

Responses to open-ended questions about how the environment around the home affected the life or health of the respondent or members of her household are shown in Tables 5 and 6. Responses that were given by two or more persons in the study are shown. Most participants from the control and cattle communities had little to report in response to these open-ended questions, although eight participants in the cattle community mentioned livestock odor. In contrast, livestock odor was noted as a problem for many residents of the hog community and for members of the residents' households.

Discussion

To our knowledge this is the first population-based study of physical health symptoms and

Table 4. Linear regression results: average number of episodes in two livestock communities as compared to a community with no intensive livestock.

	Livestock operation					
	Cattle			Hogs		
Symptom	β[a]	SE[b]	*t*-Value	β[a]	SE[b]	*t*-Value
Upper respiratory/sinus						
Headache	1.57	3.02	0.52	7.62	2.94	2.60
Stuffy nose/sinuses	1.33	2.86	0.47	2.97	2.79	1.06
Runny nose	1.26	2.44	0.52	5.18	2.37	2.18
Burning nose/sinuses	-0.42	2.19	-0.19	1.99	2.13	0.93
Sore throat	1.71	1.52	1.12	3.64	1.48	2.45
Plugged/popping ears	-1.07	2.28	-0.47	-0.79	2.22	-0.35
Scratchy throat	1.63	1.49	1.09	2.09	1.45	1.44
Lower respiratory						
Mucus/phlegm	0.56	2.65	0.21	3.91	2.57	1.52
Excessive coughing	2.15	2.06	1.04	4.74	2.01	2.36
Shortness of breath	-1.62	2.66	-0.61	-0.74	2.59	-0.29
Tightness in chest	1.45	2.08	0.70	1.37	2.02	0.68
Wheezing	-0.63	2.05	-0.31	-0.50	1.99	-0.25
Strange breathing sounds	-2.31	2.16	-1.07	-2.57	2.09	-1.23
Gastrointestinal						
Heartburn	2.35	2.86	0.82	1.94	2.78	0.70
Nausea/vomiting	1.15	2.20	0.52	3.46	2.15	1.61
No appetite	0.92	2.02	0.46	3.03	1.96	1.55
Diarrhea	-0.92	1.44	-0.64	2.96	1.39	2.13
Skin/eye irritation						
Burning eyes	-1.39	2.47	-0.56	5.58	2.42	2.31
Tearing eyes	-1.70	3.24	-0.52	0.64	3.16	0.20
Dry/scaly skin	1.85	2.81	0.66	2.67	2.74	0.98
Skin rash or irritation	0.54	1.72	0.31	2.28	1.67	1.36
Skin redness	-1.25	1.01	-1.23	0.12	0.99	0.12
Miscellaneous						
Joint/muscle pain	-0.22	4.03	-0.06	1.22	3.93	0.31
Unexplainably tired	-3.43	3.78	-0.91	0.76	3.68	0.21
Blurred vision	-4.67	3.14	-1.49	1.25	3.07	0.41
Dizzy/faint	-1.22	2.17	-0.56	-1.32	2.11	-0.63
Hearing problems	-6.44	2.50	-2.57	-3.58	2.44	-1.47
Chest pain	-2.30	1.32	-1.74	-0.35	1.29	-0.27
Fever/chills	-1.32	1.04	-1.27	-0.39	1.02	-0.38
Fainted	-0.18	0.86	-0.20	1.02	0.84	1.21
Quality of life						
Can't open windows	-1.33	2.88	-0.46	14.74	2.80	5.26
Can't go outside	-0.79	2.38	-0.33	12.73	2.32	5.47

[a]Difference in the average number of episodes between communities with and without livestock operations, adjusted for sex, age, smoking, and work outside of the home. [b]Of the β-coefficient.

quality of life among community residents in North Carolina that focused on the possible health effects of airborne emissions from intensive livestock operations. The study sample was drawn from areas of the state with a majority of African American residents who have low median income. This was not unexpected because intensive hog operations in North Carolina are located disproportionately in poor and nonwhite areas (*27*). Despite the legacy of distrust of biomedical research in the African American community (*28*), refusal rates were low because of the participation of community based organizations in introducing researchers to participants. The preponderance of women in the study reflects, in part, who was at home and who answered the door when approached by the community consultant and interviewer.

A number of symptoms previously reported as elevated among persons occupationally exposed in swine confinement houses were elevated among the residents of the hog community as compared to the community with no livestock operations. In particular, headache, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes were reported more frequently in the hog community. Members of the cattle community did not report similar elevations, nor did they report reduced quality of life. The quality of life measures (not opening of windows and not going outside even in nice weather) showed a large excess in the hog community.

As in all studies, measurement problems and differences between the communities other than the exposure of interest could have influenced the results. Recall bias is an issue in any survey. We were particularly concerned that residents living in proximity to a hog operation might report a greater number of symptoms because of negative feelings about the effect of the operation on their lives and their community. Therefore, we were careful to present the study as a rural health survey, not as a livestock and health study, and we did not include any questions in the survey that referred to hogs, livestock, or odors. During debriefings after the field work, interviewers reported that some respondents did not understand that questions about the environment referred to problems including odor. Such misunderstandings would have led to an underestimate of the impact of livestock operations on health and quality of life.

It is possible that residents of the hog community could have reported more symptoms because of their feelings about the negative impact of the hog operation on their community. However, if this had occurred, we would have expected excess reports for most symptoms. In fact, the eight symptoms in the miscellaneous category, none of which were expected to be related to exposure to airborne emissions, occurred with about the same frequency in the hog and control communities (Table 4). This suggests that there was not a tendency for over-reporting among residents of the hog community. Negative feelings might also have been evident in the open-ended questions, when respondents had the opportunity to report concerns beyond the environmental health and quality-of-life issues addressed in the structured questionnaire. As shown in Table 6, two persons in the hog community expressed concerns about property values.

Other circumstances of the survey may have led to an underestimate of the impact of swine operations on health of area residents. Perhaps most important, we studied an area with only one intensive hog operation. We would have expected to see larger effects in areas of the state with larger and more numerous operations and consequently heavier airborne emissions. Differences between the livestock and control communities may also have been reduced because of exposures to agricultural chemicals and dusts from row cropping in the control community.

Levels of emissions and weather conditions at the time interviewers were in the field may also have influenced the findings. With one exception, interviewers did not notice an odor from the hog operation while conducting the interviews. If interviews had been conducted when odors were strong, respondents may have reported a greater frequency of health symptoms.

The lack of environmental exposure monitoring data is also a concern in this study. We assumed that if persons resided within 2 miles of the hog operations, they were exposed to the emissions. We were not able to distinguish higher or lower exposure levels within the community. Exposure differences could occur because of differences in distance, direction, elevation, physical barriers, the amount of time spent at home, the amount of time spent outdoors, and the availability of air conditioning and filters in the home. Quantitative evaluation of exposure differences between individuals would increase the ability of an epidemiologic study to identify health effects of airborne emissions.

Similarly, clinical or biologic measures of outcome would strengthen information about relationships between environmental exposures to emissions from livestock operations and health. Future studies could be designed to obtain information on respiratory and immune function and standardized clinical evaluation of physical and mental health conditions. Such studies could evaluate possible mechanisms linking environmental exposures and health.

This study was not able to evaluate specific populations that may be more susceptible to health impacts of environmental exposures. These groups include children, asthmatics, and older persons with compromised pulmonary or cardiovascular function. Future studies should evaluate whether these subgroups are more sensitive to airborne emissions from intensive livestock operations. We were also unable to evaluate the acute impact of odors on mental health or the long-term impacts of reduced quality of life on mental, physical, or community health.

This study supports previous research suggesting that community members experience health problems due to airborne emissions from intensive swine operations (*7*). In North Carolina there are approximately 2,500 intensive hog operations, and they are located disproportionately in areas that are poor and nonwhite (*27*). The public health

Table 5. Problems that affect respondents' own life or health.[a]

Problem	Livestock operation		
	None	Cattle	Hogs
Livestock odor	0	8	25
Livestock odor (limits adult recreation)	0	0	14
Livestock odor (respiratory symptoms)	0	0	6
Livestock odor (can't open windows)	0	0	4
Livestock effluent (contaminated well)	0	0	4
Livestock odor (try not to breathe)	0	0	3
Livestock odor (nausea)	0	0	3
Livestock operation (flies and insects)	0	0	3
Crop sprayers (dust or noise)	1	0	2

[a]Respondents were asked, "Has the environment around your house affected your life and health?"

Table 6. Problems that affect family members' life or health.[a]

Problem	Livestock operation		
	None	Cattle	Hogs
Livestock odor	0	0	18
Livestock odor (limits child recreation)	0	0	10
Livestock odor (limits adult recreation)	0	1	4
Livestock odor (try not to breathe)	0	0	4
Livestock odor (respiratory symptoms)	0	0	4
Respiratory ailments	3	0	3
Complaints of skin symptoms	1	0	2
Livestock effluent (contaminated well)	0	0	2
Livestock odor (decreases property value)	0	0	2

[a]Respondents were asked, "Has the environment around your house affected the life or health of other members of your household?"

and environmental injustice implications of this geographical pattern extend beyond the physiologic impact of airborne emissions to issues of well-water contamination (*29*) and the negative impact of noxious odors (*8*) on community economic development (*30,31*). Populations in these areas may be at greater risk of health impacts due to high disease rates (*32,33*), low income (*27*), and poor housing conditions. Future research could provide a better understanding of the health effects of intensive livestock operations by combining individual exposure assessment, physiologic measures, clinical evaluation of physical and mental health, and follow-up of exposed communities.

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Exhibit 5 to the
Declaration of Professor Steven B. Wing, Ph.D.

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Asthma Symptoms Among Adolescents Who Attend Public Schools That Are Located Near Confined Swine Feeding Operations

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ARTICLE

Asthma Symptoms Among Adolescents Who Attend Public Schools That Are Located Near Confined Swine Feeding Operations

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ABSTRACT

OBJECTIVES. Little is known about the health effects of living in close proximity to industrial swine operations. We assessed the relationship between estimated exposure to airborne effluent from confined swine feeding operations and asthma symptoms among adolescents who were aged 12 to 14 years.

METHODS. During the 1999–2000 school year, 58 169 adolescents in North Carolina answered questions about their respiratory symptoms, allergies, medications, socioeconomic status, and household environments. To estimate the extent to which these students may have been exposed during the school day to air pollution from confined swine feeding operations, we used publicly available data about schools ($n = 265$) and swine operations ($n = 2343$) to generate estimates of exposure for each public school. Prevalence ratios and 95% confidence intervals for wheezing within the past year were estimated using random-intercepts binary regression models, adjusting for potential confounders, including age, race, socioeconomic status, smoking, school exposures, and household exposures.

RESULTS. The prevalence of wheezing during the past year was slightly higher at schools that were estimated to be exposed to airborne effluent from confined swine feeding operations. For students who reported allergies, the prevalence of wheezing within the past year was 5% higher at schools that were located within 3 miles of an operation relative to those beyond 3 miles and 24% higher at schools in which livestock odor was noticeable indoors twice per month or more relative to those with no odor.

CONCLUSIONS. Estimated exposure to airborne pollution from confined swine feeding operations is associated with adolescents' wheezing symptoms.

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Key Words
asthma, environmental health, epidemiology, school age children, school health

Abbreviations
CAFO—confined animal feeding operation
PR—prevalence ratio
NCSAS—North Carolina School Asthma Survey
SSLW—steady-state live weight
CI—confidence interval

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DURING THE PAST 2 decades, the process of raising swine and other livestock has grown into a major industry in the United States. Production has shifted from smaller, family-owned farms to larger, industrialized confined animal feeding operations (CAFOs). Animals in North Carolina's industrialized operations are raised in confinement buildings, housing hundreds to thousands of hogs per operation. Residues of food additives, bedding, dried waste, and animal dander are vented from confinement buildings, and animal waste from the confinement houses is flushed into on-site cesspools, where it begins to decompose and aerosolize anaerobically before being sprayed onto nearby land. There are concerns about the health impacts of exposure to particulate matter, antibiotic residues, volatile organic compounds, and bioaerosols that are present in air that is downwind from confinement buildings, waste lagoons, and spray fields.[1–4]

In occupational settings, adverse respiratory symptoms and changes in bronchial responsiveness and lung function have been observed among confinement building workers.[5–12] Studies that have compared swine CAFO neighbors with other rural residents showed that neighbors reported more frequent respiratory symptoms and mucosal membrane irritation.[13] This literature about health impacts of residential exposures that arise from CAFOs focuses on adults[2,13–15] and may describe inadequately the potential respiratory health effects among children, who may experience notably different physical, educational, and social impacts from such exposures. We designed this research to assess the relationship between self-reported wheezing symptoms among adolescents who were aged 12 to 14 years and estimated exposure to airborne effluent from swine CAFOs.

METHODS

This study combined data about adolescents' respiratory health symptoms, data from a survey of school environments, and location data about swine CAFOs and public schools in North Carolina. Random-intercepts binary regression models were used to estimate prevalence ratios (PRs) that assessed the association between airborne swine pollutants and the prevalence of wheezing symptoms.

North Carolina School Asthma Survey Data

During the 1999–2000 school year, the North Carolina Department of Health and Human Services conducted a statewide respiratory health surveillance project to assess the prevalence of respiratory symptoms among middle school–aged children.[16] Approximately 67% (128 568 of 192 248) of all eligible students participated in the survey, which included core wheezing questions from the International Study of Asthma and Allergies in Childhood questionnaire, a standardized and validated instrument that combines a traditional written questionnaire with a series of video scenes that show children with asthma symptoms.[17–20] To complete the video-based survey questions, students viewed a sequence of video vignettes that showed adolescents experiencing asthma-related symptoms; each scene was followed by time to complete a written survey question, allowing each student to indicate whether he or she had experienced symptoms like those illustrated in the scene.[19,20] We analyzed the prevalence of any wheezing symptoms within the past year ("current wheezing"), as determined by responses to questions about wheezing at rest, waking at night as a result of wheezing, exercise-induced wheezing, and severe wheezing attacks. The definition of current wheezing used here is consistent with that applied in previous analyses of the North Carolina School Asthma Survey (NCSAS) data.[16,21–23]

To evaluate whether the estimated exposure had an impact other asthma-related outcomes, we assessed "severe wheezing" using responses to survey questions about waking at night as a result of wheezing and having a severe wheezing attack during the past year; considered the severe wheezing symptoms to be frequent when they occurred at least once per month ("frequent severe wheezing"); and evaluated physician-diagnosed asthma, medical care, and behavioral consequences of asthma-related symptoms.

Each adolescent also answered questions about age, race, Hispanic ethnicity, allergies, socioeconomic status, cigarette smoking history, and home environment. We included age as a continuous variable (centered at 13) and categorized all other variables: race (black/white); Hispanic ethnicity (yes/no); allergies to cat, dog, dust, grass, or pollen (yes/no); ever smoked cigarettes (yes/no); number of other smokers in household (0, 1, 2, or ≥3); and use of a gas stove at home (<1 time per month vs ≥1 times per month). Socioeconomic status was assessed using responses to a question about payment for lunch at school, with lower economic status designated by receiving free or reduced-price lunch at school compared with paying full price for lunch or bringing lunch to school.

School Environment Data

During the 2003–2004 school year, we mailed 4 copies of a survey to principals of 337 public schools and asked each to distribute the surveys to current school employees. More than 800 anonymous survey respondents, employed in 265 (79%) of the targeted schools, answered questions about their observations of the environmental conditions in and around the school buildings. The survey responses indicated whether there was visible evidence of the presence of cockroaches, rodents, or mold and noticeable odors from indoor (eg, mold) and outdoor (eg, nearby industries) sources of airborne pollutants. Responses were used to create school-level indicator variables for the presence of indoor respiratory irritants and sources of outdoor air pollution from agriculture and industries that are located near the school. Because of concerns about response bias resulting from social and political conflict surrounding industrial swine production in North Carolina, we asked survey respondents to answer a question about livestock odor generically rather than about odor specifically arising from swine operations. When we received >1 survey from a single school, schools were categorized as positive for a given survey question when any respondent reported the given condition.

Swine CAFO Exposure Estimates

Estimates of exposure to airborne pollution from 2343 swine CAFOs were generated using data from permits that were issued by the North Carolina Division of Water Quality to all CAFOs that house at least 250 animals and use a liquid waste management system. Records contained mandatory information about each CAFO facility, including geographic coordinates and the number, type, and weight of animals (called steady-state live weight [SSLW]) at each operation.[3,24] CAFO operators who filed applications for liquid waste management permits with the state agency provided latitude and longitude coordinates of their operations; the coordinates were verified and corrected, when necessary, when state inspectors visited the operations, although the extent to which the information was corrected by agency inspectors was not recorded in the data (S. Lewis, personal communication, 2002).

Separate exposure estimates were developed on the basis of distances between schools and swine CAFOs and of survey responses about noticeable odors from livestock farms. Distances and geographic directions between schools and CAFOs were calculated using the formulas given by Goldberg et al[25] and Sinnott,[26] respectively. We used calculations of proximity to create 3 metrics of potential exposure for each school: (1) distance to the nearest operation; (2) SSLW within 3 miles; and (3) a weighted SSLW based on the distance between the school and nearby swine CAFOs, the SSLW of each operation, and the proportion of wind measurements in the direction from the operation to the school. We obtained measurements of wind speed and direction recorded at 16 automated weather stations located throughout the state from the State Climate Office of North Carolina (Raleigh, NC). Hourly averages from January 1999 through December 1999 and from the weather station located nearest each school–CAFO pair were used to compute the proportion of time when the wind was blowing from the operation to the school. Weighted SSLW values for each CAFO within 3 miles of a school were the product of the squared inverse of the distance between the school–CAFO pair, the operation's SSLW value, and the proportion of time that regional wind measurements indicated that wind was blowing from the operation toward the school. For each school, weighted SSLW values were summed and the schools were assigned categories of low, medium, and high exposure on the basis of tertiles of the distribution of values among schools with 1 or more swine CAFOs located within 3 miles. A 3-mile radius was selected on the basis of previous research about the impacts of swine CAFOs on health and quality of life among neighbors who live within a 2-mile radius[2,13]; for this research, we expanded the potential zone of exposure to 3 miles because odors from swine CAFOs sometimes are reported at distances of >2 miles.

Study Population

Students in 499 public schools participated in NCSAS, and each student provided data about his or her respiratory health. Schools in 14 counties that did not contain a swine CAFO or border a county with at least 1 swine CAFO ($n = 45$), schools within the city limits of the 6 cities with populations >100 000 ($n = 61$), schools within 5 miles of the state border ($n = 18$), schools with <25 students surveyed ($n = 34$), schools that had closed or relocated since 2000 ($n = 11$), and schools that did not respond to the survey about in-school environmental conditions ($n = 72$) were excluded from our study. The remaining 265 public schools were included in our study. From these 265 schools, a total of 73 305 boys and girls who were aged 12 to 14 years responded to NCSAS. Of those, 58 169 (79%) who reported black or white race and provided complete data for all asthma survey variables of interest constituted our final study population.

Statistical Analyses

Multivariate analyses were conducted separately for individuals with and without self-reported allergies to cat, dog, dust, grass, and/or pollen. To assess the relationship between the prevalence of wheezing symptoms and the estimates of in-school exposure, we used random-intercepts binary regression. This method accounted for the hierarchical clustering of student-level data within schools. Specifically, we used a variation of the generalized linear mixed model $E(Y x) = \exp(\alpha + \Sigma\beta x)$ similar to those described by Singer[27] and McLeod,[28] in which the student's outcome is modeled by a combination of student-level (level 1) and school-level (level 2) models. The student-level model was defined as

$$\log_e(P_{ij}) = \beta_{0j} + \beta_1 x_{1j} + \beta_2 x_{2j} + \ldots + \beta_n x_{nj} \text{ (level 1)},$$

where P_{ij} is the probability of outcome $y = 1$ for individual i in school j, $p_{ij} \sim$ binomial; β_{0j} is school-specific intercept (intercept for school j); and β is the effect of individual-level predictor x_{ij}. Level 1 models included student-level variables for age, gender, race, Hispanic ethnicity, economic status, allergy status, cigarette smoking experience, number of other smokers in the household, and use of a gas kitchen stove at home. The school-level (level 2) model was defined as

$$\beta_{0j} = \beta_0 + \mu_1 z_1 + \mu_2 z_2 + \ . \ . \ . + \mu_n z_m + \mu_{0j} \text{ (level 2)},$$

where β_0 is the mean of school-level means for outcome y (ie, fixed intercept); μ is the effect of school-level predictor z_j; z_j is the school-level predictor for school j; $\mu_{0j} \sim N(0,\tau_{00})$; and τ_{00} is between-school variance. The level 2 models included main exposure variable(s) and indicator variables for rural school locale, survey-reported presence of indoor respiratory irritants (cockroaches, rodents, mold visible, mold odor, or flooding of school buildings within the past 5 years), and survey-reported industry other than a swine CAFO located near the school. The level 2 model, substituted into the level 1 model, results in a final 2-level random-intercepts model,

$$\log_e(P_{ij}) = \beta_{0j} + \beta_1 x_{1j} + \beta_2 x_{2j} + \ . \ . \ . + \beta_n x_{nj} + \mu_1 z_1 + \mu_2 z_2 + \ . \ . \ . + \mu_n z_m + \mu_{0j},$$

where μ_{0j} is the random intercept term. Associations were estimated as PRs (exp[μ]) using SAS statistical software version 8.2 (SAS Institute Inc, Cary, NC).

RESULTS

More than 26% (15 250 of 58 169) of students who participated in NCSAS during the 1999–2000 school year reported wheezing during the past year (ie, current wheezing). Table 1 shows adjusted PRs for individual- and school-level characteristics. Of the individual-level characteristics, the highest PR was observed for self-reported allergy status (PR: 2.20; 95% confidence interval [CI]: 2.14–2.27). Variations in the prevalence of current wheezing by school-level characteristics and indicators of school-specific environmental health conditions were less pronounced.

Of the 265 schools, 66 (25%), including 10 518 (18%) surveyed students, were located within 3 miles of at least 1 (range: 1–27) swine CAFO. More than 50% of the schools were within 7 miles of the nearest operation (median: 6.7 miles; range: 0.22–42.0 miles). The average SSLW capacity of operations that were located within 3 miles of a school was slightly lower than that of operations that were located beyond 3 miles (556 283 lb vs 605 139 lb), and, overall, the SSLW capacity of swine CAFOs increased with increasing distance from the nearest surveyed school (β [SE] per mile = 15 948 [4791]). On the basis of the environmental health surveys and according to survey respondents, livestock odor was noticeable outside buildings in 86 (33%) schools and inside the buildings in 39 (15%) schools.

Table 2 presents adjusted PRs for wheezing using each exposure measure separately for students with and without allergies. PRs were 1.05 (95% CI: 1.00–1.10) and 1.02 (95% CI: 0.94–1.11) for adolescents who did and did not have allergies, respectively, and attended schools that were located within 3 miles of the nearest swine CAFO. PRs were approximately unity for schools that were closer than 2 miles, compared with schools with no nearby swine CAFOs, and were 1.12 (95% CI: 1.04–1.19) and 1.08 (95% CI: 0.95–1.21), respectively, for students who did and did not have self-reported allergies and attended schools that were located between 2 and 3 miles from the nearest operation. Associations with SSLW and the weighted SSLW exposure categories also tended to be highest for the low exposure groups and closer to unity for higher exposure groups compared with schools with no nearby swine CAFOs. Basing potential exposure estimates on survey-reported livestock odor resulted in 20 fewer schools' and 3315 fewer adolescents' being considered unexposed. The prevalence of current wheezing was 24% and 21% higher among allergic and nonallergic students, respectively, at schools in which livestock odor was noted inside the school building 2 or more times per month relative to the prevalence at schools without any survey reports of livestock odor.

Table 3 presents adjusted associations between school proximity within 3 miles of a swine CAFO and alternative asthma outcomes as well as functional consequences of asthma-related symptoms. Results indicate that larger proportions of adolescents who attended school near at least 1 swine CAFO experienced respiratory symptoms, physician diagnosis, asthma-related medical treatment, activity limitations, and missing school because of their symptoms. In the population of all students, the largest PRs were observed for physician-diagnosed asthma (PR: 1.07; 95% CI: 1.01–1.14), medication use (PR: 1.07; 95% CI: 1.00–1.15), and visit to a physician or an emergency department or hospitalization (PR: 1.06; 95% CI: 1.00–1.12). Most associations were slightly higher in adolescents with self-reported allergies; however, the PR for physician-diagnosed asthma was higher among students without (PR: 1.14; 95% CI: 1.01–1.26) compared with those with (PR: 1.06; 95% CI: 0.99–1.12) self-reported allergies. Adjusted associations between these outcomes and the presence of livestock odor in and around the schools indicate only slightly elevated proportions of wheezing symptoms, physician diagnosis, use of asthma-related medical care, activity limitations, and missed school among students in schools where employees reported noticeable livestock odor (Table 4). When school-level exposures were assigned on the basis of reported livestock odor (Table 4), the PRs for severe wheezing (PR: 1.05; 95% CI: 1.00–1.10) and frequent severe wheezing (PR: 1.06; 95% CI: 0.98–1.14) were higher than when exposure was assigned on the basis of distance to the nearest swine CAFO (severe wheeze, ≤3 miles: 1.02 [95% CI: 0.97–

TABLE 1 **Characteristics of North Carolina School Asthma Survey Participants and Public Schools in North Carolina**

	N	Students Who Reported Current Wheezing, *n* (%)	PR (95% CI)[a]
Total	58 169	15 250 (26.2)	—
Age, y[b]			
12	17 905	4873 (27.2)	1.06 (1.04–1.08)
13	28 130	7268 (25.8)	1.00[c]
14	12 134	3109 (25.6)	0.95 (0.93–0.96)
Race			
White	43 590	10 919 (25.1)	1.00
Black	14 579	4331 (29.7)	1.04 (1.01–1.08)
Gender			
Male	28 342	6798 (24.0)	1.00
Female	29 827	8452 (28.3)	1.07 (1.04–1.10)
SES indicator			
Lunch not subsidized	41 719	10 088 (24.2)	1.00
Lunch subsidized	16 450	5162 (31.4)	1.16 (1.12–1.20)
Hispanic ethnicity			
No	54 827	14 236 (26.0)	1.00
Yes	3342	1014 (30.3)	1.11 (1.06–1.16)
Allergies			
No	31 480	5149 (16.4)	1.00
Yes	26 689	10 101 (37.9)	2.20 (2.14–2.27)
Ever smoked			
No	40 632	9154 (22.5)	1.00
Yes	17 537	6096 (34.8)	1.35 (1.31–1.39)
No. of other smokers in household[b]			
0	27 662	6138 (22.2)	1.00
1	16 079	4447 (27.7)	1.09 (1.07–1.10)
2	10 209	3178 (31.1)	1.18 (1.15–1.21)
≥3	4219	1487 (35.3)	1.29 (1.24–1.34)
Frequency of gas kitchen stove use			
Less than once per more	45 546	11 384 (25.0)	1.00
Once per month or more	12 623	3866 (30.6)	1.14 (1.11–1.17)
Rural school locale			
No	30 154	8074 (26.8)	1.00
Yes	28 015	7076 (25.6)	0.96 (0.92–1.00)
In-school asthma triggers[d]			
No	4619	1147 (24.8)	1.00
Yes	53 550	14 103 (26.3)	1.03 (0.95–1.11)
Location near non-livestock industry[e]			
No	52 184	13 603 (26.1)	1.00
Yes	5985	1647 (27.5)	1.06 (0.99–1.13)

PR indicates prevalence ratio; SES, socioeconomic status.
[a] Adjusted for all individual-level and school-level covariates in the table.
[b] Included in the model as a continuous variable.
[c] Referent category.
[d] Environmental Health Survey responses about cockroaches, rodents, mold, and/or flooding in school buildings (no: 24 schools; yes: 241 schools).
[e] Environmental Health Survey responses about non-livestock industries located near the school (No: 236 schools; Yes: 29 schools).

1.07]; frequent severe wheeze, ≤3 miles: 1.01 [95% CI: 0.92–1.09]; Table 3).

DISCUSSION

We observed elevated prevalences of current wheezing among 12- to 14-year-old students who attended public schools near swine CAFOs, especially among students with self-reported allergies. Such associations are plausible, given that swine CAFOs are sources of bioaerosols, endotoxins, and other airborne asthma triggers. The availability of standardized symptom data and the independence of symptom and exposure data strengthen confidence in the validity of our findings. Overall, estimates of excess current wheezing symptoms among students who attended schools nearby swine CAFOs are as high as 24% among students who attended schools where livestock odor was reported outside as well as inside 2 or more times per month. Excess prevalence of current wheezing tended to be greater among students who reported allergies. Although the majority of the

TABLE 2 Associations Between the Prevalence of Wheezing and Exposure to Confined Swine Feeding Operations by Adolescents' Self-Reported Allergic Status, North Carolina

	Total No. of Schools	Self-Reported Allergies (n = 26 689)			No Self-Reported Allergies (n = 31 480)			All (N = 58 169)		
		Total No. of Students	Wheeze, n (%)[a]	PR (95% CI)[b]	Total No. of Students	Wheeze, n (%)	PR (95% CI)[b]	Total No. of Students	Wheeze, (%)	PR (95% CI)[c]
Current wheeze			10 101 (37.9)			5149 (16.4)			15 250 (26.2)	
Miles to nearest swine CAFO										
>3	199	21 898	8145 (37.2)	1.00	25 753	4138 (16.1)	1.00	47 651	12 283 (25.8)	1.00
≤3	66	4791	1956 (40.8)	1.05 (1.00–1.10)	5727	1011 (17.7)	1.02 (0.94–1.11)	10 518	2967 (28.2)	1.04 (0.99–1.09)
2 to ≤3	22	1865	822 (44.1)	1.12 (1.04–1.19)	2107	396 (18.8)	1.08 (0.95–1.21)	3972	1218 (30.7)	1.10 (1.02–1.18)
≤2	44	2926	1134 (38.8)	1.01 (0.95–1.07)	3620	615 (17.0)	0.99 (0.89–1.09)	6546	1749 (26.7)	1.01 (0.95–1.07)
Hog pounds (in millions) within 3 miles of school										
None	199	21 898	8145 (37.2)	1.00	25 753	4138 (16.1)	1.00	47 651	12 283 (25.8)	1.00
0.1 to <2.0	42	3342	1388 (41.5)	1.07 (1.01–1.12)	4017	713 (17.8)	1.03 (0.93–1.12)	7359	2101 (28.6)	1.05 (1.00–1.11)
2.0 to <5.0	12	733	294 (40.1)	1.04 (0.93–1.14)	858	150 (17.5)	0.99 (0.81–1.16)	1591	444 (27.9)	1.01 (0.91–1.12)
≥5.0	12	716	274 (38.3)	1.00 (0.89–1.11)	852	148 (17.4)	1.04 (0.85–1.23)	1568	422 (26.9)	1.02 (0.91–1.13)
Exposure category										
None	199	21 898	8145 (37.2)	1.00	25 753	4138 (16.1)	1.00	47 651	12 283 (25.8)	1.00
Low	21	1655	711 (43.0)	1.10 (1.03–1.18)	1922	359 (18.7)	1.09 (0.95–1.23)	3577	1070 (29.9)	1.09 (1.01–1.18)
Medium	22	1741	771 (40.8)	1.04 (0.97–1.12)	2139	378 (17.7)	1.01 (0.89–1.13)	3880	1089 (28.1)	1.03 (0.96–1.11)
High	23	1395	534 (38.3)	1.01 (0.93–1.08)	1666	274 (16.5)	0.97 (0.84–1.10)	3061	808 (26.4)	1.00 (0.92–1.08)
Livestock odor										
None	179	19 055	7188 (37.7)	1.00	22 438	3694 (16.5)	1.00	41 493	10 882 (26.2)	1.00
Outside school only	47	4625	1766 (38.2)	1.04 (0.98–1.09)	5593	843 (15.1)	0.94 (0.85–1.02)	10 218	2609 (25.5)	1.00 (0.95–1.06)
Outside + inside <2 times/mo	36	2745	1022 (37.2)	0.99 (0.93–1.06)	3137	550 (17.5)	1.04 (0.93–1.15)	5882	1572 (26.7)	1.01 (0.94–1.07)
Outside + inside ≥2 times/mo	3	264	125 (47.4)	1.24 (1.03–1.44)	312	62 (19.9)	1.21 (0.85–1.57)	576	187 (32.5)	1.23 (1.01–1.44)

[a] Any wheeze in the past 12 months (current wheeze).
[b] Adjusted for individual-level characteristics (gender, age, race, Hispanic ethnicity, economic status, smoking status, exposure to second-hand smoke at home, and use of a gas stove more than once per month) and school-level characteristics (rural locale, indoor air quality, and reports of other non-livestock industries nearby).
[c] Adjusted for variables listed above plus self-reported allergy to cats, dogs, dust, grass, and/or pollen.

TABLE 3 Associations Between the Prevalence of Asthma-Related Symptoms and School Location Within 3 Miles of a Confined Swine Feeding Operation by Adolescents' Self-Reported Allergic Status, North Carolina

	PR (95% CI) for ≤3 vs >3 Miles From Nearest Swine CAFO		
	Self-Reported Allergies (n = 26 689)	No Self-Reported Allergies (n = 31 480)	All (N = 58 169)
Wheezing symptoms			
Current wheeze	1.05 (1.00–1.10)	1.02 (0.94–1.11)	1.04 (0.99–1.09)
Current wheeze without physician diagnosis	1.08 (1.01–1.15)	0.99 (0.90–1.08)	1.04 (0.98–1.11)
Severe wheeze[b]	1.01 (0.96–1.07)	1.05 (0.96–1.14)	1.02 (0.97–1.07)
Frequent severe wheeze[a]	1.02 (0.92–1.11)	0.97 (0.80–1.14)	1.01 (0.92–1.09)
Physician-diagnosed asthma	1.06 (0.99–1.12)	1.14 (1.01–1.26)	1.07 (1.01–1.14)
Medical care			
Asthma-related physician visit, emergency visit, and/or hospitalization in past year	1.06 (1.00–1.13)	1.03 (0.92–1.13)	1.06 (1.00–1.12)
Asthma medication use in past year	1.09 (1.00–1.18)	1.03 (0.88–1.18)	1.07 (1.00–1.15)
Functional consequences of symptoms			
Activity limitations in past year as a result of asthma symptoms	1.09 (1.01–1.16)	—[b]	—
Missed school in past year as a result of asthma symptoms	1.06 (0.98–1.14)	—	—

[a] Among individuals with current wheeze.
[b] Nonconvergent model.

estimates are small in relative terms, the increases are important in absolute terms because of the high prevalence of asthma-related symptoms in this age group; the impact that symptoms have on adolescents' ability to attend school and participate in social, recreational, and physical activities; and the costs and burdens of symp-

TABLE 4 **Associations Between the Prevalence of Asthma-Related Symptoms and the Presence of Livestock Odor at the School by Adolescents' Self-Reported Allergic Status, North Carolina**

	PR (95% CI) for Livestock Odor Reported Outside or Inside School Building Versus No Reported Odor		
	Self-Reported Allergies (*n* = 26 689)	No Self-Reported Allergies (*n* = 31 480)	All (*N* = 58 169)
Wheezing symptoms			
Current wheeze	1.03 (0.98–1.07)	0.99 (0.91–1.06)	1.01 (0.97–1.06)
Current wheeze without physician diagnosis	1.04 (0.97–1.10)	0.99 (0.90–1.07)	1.01 (0.96–1.07)
Severe wheeze[a]	1.06 (1.01–1.12)	1.00 (0.91–1.08)	1.05 (1.00–1.10)
Frequent severe wheeze[a]	1.04 (0.95–1.14)	1.10 (0.92–1.28)	1.06 (0.98–1.14)
Physician-diagnosed asthma	1.00 (0.94–1.06)	1.04 (0.93–1.15)	1.01 (0.95–1.06)
Medical care			
Asthma-related physician visit, emergency visit, and/or hospitalization in past year	0.99 (0.94–1.05)	1.01 (0.91–1.10)	1.00 (0.95–1.05)
Asthma medication use in past year	1.03 (0.96–1.11)	1.02 (0.89–1.15)	1.03 (0.96–1.10)
Functional consequences of symptoms			
Activity limitations in past year as a result of asthma symptoms	1.02 (0.96–1.08)	—[b]	—
Missed school in past year as a result of asthma symptoms	1.02 (0.94–1.09)	—	—

[a] Among individuals with current wheeze.
[b] Nonconvergent model.

tom-related medical care. In these data, the effect estimates for swine CAFO exposures are of similar magnitude to the effects that have been estimated for established risk factors for wheeze, such as age, race, gender, economic status, Hispanic ethnicity, exposure to secondhand cigarette smoke, and use of a gas stove at home.

We estimated potential exposure on the basis of distance and a mailed survey. Although distance is a crude measure of exposure, our findings suggest a consistent trend toward higher symptom prevalence, especially among adolescents with allergies, at schools that were between 2 and 3 miles of a swine CAFO. The finding that schools that were located within 2 miles had a lower prevalence of current wheezing may reflect the lack of a direct relationship between exposure to etiologically active agents and distance. Use of distance and SSLW as exposure measures does not take account of waste management and sanitation practices of swine CAFOs, ages and conditions of the facilities' equipment, localized weather patterns, topography surrounding the school, school building structure, and ventilation practices, all of which may affect the quantity and the duration of the exposures. In addition, swine CAFO practices such as waste and sanitation procedures may be influenced by population density, land availability, and other features of the communities in which the operations are located, although we do not know the extent to which this occurs. Indeed, results of analyses that used exposure metrics of increasing complexity failed to show a monotonic dose-response relationship between the exposure and current wheezing, further suggesting that if the exposure is associated with an increase in respiratory symptoms, then relevant exposure may not correlate directly with the factors that we used for our distance-based exposure categories.

The higher prevalence of current wheezing among students who attended schools that were located 2 to 3 miles from the nearest swine CAFO compared with the prevalence among students who attended schools within 2 miles also may be attributable to exposures that were experienced at home, in the communities where students lived, and in other locations that could not be assessed in our study. In many of the rural areas in North Carolina, students may live many miles from the public schools that they attend. As the distance between the school and the CAFO becomes small, few homes can be equally close or closer to a CAFO; as the distance increases, more of the students' homes can be located closer to a CAFO than the distance between the CAFO and the school, and school-based exposure estimates will underestimate students' total swine CAFO exposures. In addition, reports of odor from swine CAFOs tend to be more common in early morning and evening hours rather than in the daytime, when students are in school. Although this phenomenon may not affect exposures in geographic areas where both schools and homes are far from CAFOs, identifying exposure as the distance between a school and a CAFO may be more problematic in regions where schools are located very near or within several miles of CAFOs if exposure varies throughout the day. Previous research that was conducted in a rural population of school-aged children who may have experienced swine farm exposures at home indicated a higher prevalence of asthma-related symptoms among children who lived on farms where swine were raised than among children who lived on farms where swine were not raised and among children who did not live on farms,[29] although the extent to which exposures that resulted from residence on a swine farm were attributable to performing chores or occupation-like tasks, rather than simply living close to swine, are unknown. Although information about adolescents' household farming exposures are unavailable in our study population, the majority of swine in North Carolina are raised in nonresidential, factory farm settings; therefore, the proportion of children who perform chores or live on swine farms is expected to be low.

Results of analyses of the distance-based measures of each exposure suggest lower prevalence of wheezing among students who attended schools that were located nearest to CAFOs and located in areas with the highest density of swine compared with those in the highest exposure categories. To assess potential misclassification of exposure, we excluded from all analyses schools with reported livestock odor from the unexposed distance-based categories, schools that were located beyond 3 miles of swine CAFO from the exposed survey-based categories, and schools for which survey respondents specifically identified livestock odor as arising from poultry and found no notable differences in the direction, magnitude, or precision of the PRs generated. An alternative explanation for the lower prevalence of wheezing among students in schools that were located nearby swine CAFOs may be the hygiene hypothesis, which postulates that early-life exposures and childhood infections may confer protection against hay fever, atopy, and asthma.[30,31] Specifically, rural living and early-life exposures to allergens, irritants, and other bioaerosols on farms may be associated with lower rates of atopy and asthma.[29,32–38] In our study, the prevalence of wheezing was slightly lower (−1.2%) in rural compared with nonrural schools. Although we could not assess early-life exposures, higher exposures to animal dander and bacterial endotoxin during early developmental stages among individuals who attend schools closest to swine CAFOs and therefore often live in rural areas could provide some resistance to exposures later in childhood and lead to lower prevalence of wheezing during adolescence compared with students who attend schools farther away.

Twenty-one percent ($n = 72$) of schools were excluded from our final analysis because of nonparticipation in our mailed survey about in-school environmental conditions. When we compared the populations of schools that participated and those that did not, we found differences in mean distance to the nearest swine CAFO (participating schools: 8.7 miles; nonparticipating schools: 8.0 miles), percentage of nonwhite enrollment (participating schools: 36%; nonparticipating schools: 42%), and percentage of enrolled students who received subsidized school lunches (participating schools: 48%; nonparticipating schools: 51%). Systematic differences between participating and nonparticipating schools in levels of exposure and prevalences of asthma-related symptoms could have influenced our findings.

We received up to 7 completed surveys per school, and for each survey question, we assigned an exposure to a school when any respondent indicated the presence of the exposure. This method of classifying schools' environmental conditions and, in particular, the presence of livestock odor at the school was sensitive to the number of surveys completed and returned from each school and did not take into account the variation in survey responses from a single school. Our intention was to survey employees in several occupations who would be familiar with different aspects of the school building and students' behaviors: teacher, administrator, maintenance or custodial staff, and school nurse or health care personnel. Previous literature about the economic, political, and social impacts of a strong swine industry presence in communities in Iowa and North Carolina suggested that residents who live near swine CAFOs may be reluctant to voice their concerns for fear of social ostracism or conflict in their communities.[39–42] Although our school survey was anonymous and designed to minimize risks for deductive disclosure of respondents' identities, we recognize the possibility that respondents may have underreported livestock odor out of concern for expressing their opinions, and we cannot know fully the extent to which our survey reports were influenced by the social and political context in the communities in which the schools were located.

Lack of data on medical risk factors, environmental asthma triggers, and classification of allergic status on the basis of survey reports rather than of a clinical assessment of atopy are limitations of this study. Because students self-identified asthma-related symptoms, our current wheezing variable may include other respiratory symptoms that the respondents experience and mistake for the symptoms that were illustrated in the video scenes. Cross-sectional asthma-related symptom data and survey-based exposure data prohibit specific assessment of temporal relationships between the symptoms and exposures evaluated here. Our findings are vulnerable to systematic error if students with asthma-related symptoms changed their environments or behaviors because of symptoms that were caused by exposure to airborne pollution that arose from swine CAFOs; such a systematic error would lead to underestimation of associations between swine CAFOs and asthma symptoms.

CONCLUSIONS

This research was designed to estimate exposures to a source of air pollution that is of great concern to swine CAFO neighbors and to investigate relationships between school exposures and respiratory health of middle school–aged children. Our findings identify a plausible association between exposure to airborne pollution from swine CAFOs and wheezing symptoms among adolescents. Environmental pollution measurement and standardized clinical information about asthma symptoms and atopic status could help to determine better the magnitude and the temporality of the relationships between swine CAFO emissions and respiratory symptoms. Our findings should be used by public health personnel who are interested in understanding possible adverse respiratory health consequences of an important rural environmental exposure.

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Asthma Symptoms Among Adolescents Who Attend Public Schools That Are Located Near Confined Swine Feeding Operations

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Exhibit 6 to the
Declaration of Professor Steven B. Wing, Ph.D.

Air Pollution and Odor in Communities Near Industrial Swine Operations

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Background: Odors can affect health and quality of life. Industrialized animal agriculture creates odorant compounds that are components of a mixture of agents that could trigger symptoms reported by neighbors of livestock operations.

Objective: We quantified swine odor episodes reported by neighbors and the relationships of these episodes with environmental measurements.

Methods: Between September 2003 and September 2005, 101 nonsmoking volunteers living within 1.5 mi of industrial swine operations in 16 neighborhoods in eastern North Carolina completed twice-daily odor diaries for approximately 2 weeks. Meteorological conditions, hydrogen sulfide, and particulate matter ≤ 10 µm in aerodynamic diameter (PM_{10}) were monitored in each neighborhood. We used mixed models to partition odor variance within and between people and between neighborhoods, and to quantify relationships between environmental factors and odor.

Results: Participants reported 1,655 episodes of swine odor. In nine neighborhoods, odor was reported on more than half of study-days. Odor ratings were related to temperature, PM_{10}, and semivolatile PM_{10} in standard but not mixed models. In mixed models, odor increased 0.15 ± 0.05 units (mean ± SE) for a 1-ppb increase in H_2S, and 0.45 ± 0.14 units for a 10-µg/m^3 increase in PM_{10} at wind speeds > 6.75 miles per hour. The odds of reporting a change in daily activities due to odor increased 62% for each unit increase in average odor during the prior 12 hr (t-value = 7.17).

Conclusions: This study indicates that malodor from swine operations is commonly present in these communities and that the odors reported by neighbors are related to objective environmental measurements and interruption of activities of daily life.

Key words: agriculture, air pollution, community-based participatory research, environmental justice, epidemiology, quality of life, rural health. *Environ Health Perspect* 116:1362–1368 (2008). doi:10.1289/ehp.11250 available via *http://dx.doi.org/* [Online 5 June 2008]

There is a long history of medical interest in the health impacts of environmental malodor, from Hippocrates to William Farr, England's first Registrar General. In recent decades, scientific consideration of the health consequences of malodors has increased in the context of residential exposures to malodors from municipal solid waste landfills; wastewater treatment; land application of treated sewage sludge; industrialized animal operations; and the production, storage, and transport of industrial chemicals (Schiffman et al. 2000). Environmental malodors may prompt reports of annoyance, worry, and physical symptoms (Shusterman 2001). The extent to which malodor is an aesthetic issue versus a threat to health is a subject of scientific investigation and litigation that has important implications for environmental regulation, public health, and environmental justice (Thu 1998).

Odorant compounds can affect human health via several mechanisms (Schiffman et al. 2000; Shusterman 1992). First, at concentrations high enough to stimulate the trigeminal nerve, odorant chemicals may produce irritation of the eyes, nose, and throat, or other toxicologic effects. In this case, the toxicologic properties of the odorous molecules, rather than odor, produce symptoms. Second, via innate aversion, conditioning, or stress responses, odorant compounds can induce symptoms such as nausea, vomiting, headaches, stress, negative mood, and a stinging sensation at concentrations higher than the olfactory nerve threshold but below the trigeminal nerve threshold (Schiffman 1998; Schiffman et al. 2000; Shusterman 1992, 2001; Shusterman et al. 1991). Third, symptoms occurring in response to odorant mixtures may be due to a nonodorant component such as endotoxin, which can induce inflammation and airflow obstruction (Kline et al. 1999).

Odors may be quantified in natural settings or by laboratory analysis of ambient air samples using trained odor panels, scentometers, olfactometers, or electronic noses (Schiffman et al. 2001, 2005); however, transient and unpredictable odors are difficult to quantify. Although spontaneous reports of malodor may be quantified (e.g., Aitken and Okun 1992; Drew et al. 2007), this approach mixes variation in odor with variation in people's propensities to report odors and the limited availability of public agencies or researchers to track reports.

Research on malodors from concentrated animal feeding operations (CAFOs) and the consequences of these malodors for the health and quality of life of nearby neighbors has increased with expansion of industrial animal agriculture. Recent studies report that CAFO neighbors experience elevated levels of gastrointestinal and respiratory tract symptoms (Thu et al. 1997; Wing and Wolf 2000), wheezing and asthma (Merchant et al. 2005; Mirabelli et al. 2006; Radon et al. 2007), and decreased secretion of salivary IgA during episodes of high odor (Avery et al. 2004). Research on malodor is of interest in the context of broader impacts of industrial livestock production on energy use, diet, air and water pollution, and occupational health and safety (Donham et al. 2007; Thu 2002).

The purpose of this study was to quantify the reports of hog odors made by neighbors of swine CAFOs. To address a common limitation of research into connections between odor and health based on self-report without objective measures, we measured hydrogen

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This paper has not been subjected to the U.S. EPA's required peer and policy review, and therefore does not necessarily reflect the views of the agency and no official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

In exchange for a report and testimony, a law firm representing plaintiffs in a civil suit about impacts of an industrial swine operation on its neighbors contributed $2,000 to the University of North Carolina in support of S.W.'s research. K.T. has served as a consultant and provided testimony in civil suits regarding impacts of industrial swine operations on neighbors, and has received funding from the Iowa Pork Producers Association and the National Pork Producers Council. S.S.S. has received funding from the National Pork Board, the North Carolina Pork Council, and the Smithfield Agreement between Smithfield Foods and the State of North Carolina. The remaining authors declare they have no competing financial interests.

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sulfide, a product of anaerobic decomposition of hog waste, and particulate matter ≤ 10 μm in aerodynamic diameter (PM_{10}), which can transport odorant chemicals (Bottcher 2001); at the same time participants rated the strength of hog odor. Swine CAFOs are located disproportionately in low-income communities of color (Wilson et al. 2002; Wing et al. 2000), where fear of reprisals and community discord may discourage residents from reporting malodors and health concerns to health or environmental officials (Wing 2002), thus limiting the possibility of obtaining data about odor from public records. The Community Health Effects of Industrial Hog Operations study used community-based participatory research methods to increase the completeness and quality of data collection while promoting community organizing for environmental justice (Wing et al. 2008).

Materials and Methods

Setting and data collection. From September 2003 through September 2005 we collected data in eastern North Carolina, an area with one of the world's highest densities of swine production. Volunteers were recruited through community-based organizations. Nonsmoking adults ≥ 18 years of age who lived within 1.5 mi of at least one swine CAFO and had a freezer in their home (for storage of saliva samples) were eligible to be enrolled. Participants in each neighborhood attended a structured training session at which they practiced data-collection activities. Odor sensitivity threshold was evaluated by asking participants to choose which of two vials had an odor; one vial contained distilled water and the other contained butanol. Participants were presented up to 12 pairs of vials in series. The concentration of butanol increased 2-fold with each successive pair, beginning with 10 ppm. We defined odor sensitivity as the lowest concentration of a series of five correct choices.

Twice daily for 2 weeks (three neighborhoods chose to continue up to 7 additional days) participants sat outside their homes for 10 min at times agreed upon during the training session, usually morning and evening. They used a structured diary to report the strength of hog odor and information about health and quality of life. During their 10 min outside, participants were asked to recall the strength of hog odor inside at home, outside at home, and away from home for each hour of the day since their last diary entry. In this study we examined the ratings of hourly outdoor odor as well as hourly indoor odor reported in this portion of the diary. Participants also rated the current strength of hog odor at the end of the 10-min period. We analyzed these twice-daily odor ratings, which were made in the same locations at preselected times of day, in relation to odor sensitivity and environmental variables. Odor was rated on a 9-point scale from 0 (none) to 8 (very strong). Participants also indicated whether they had changed activities or decided not to do something because of hog odor.

We placed a small farm trailer with air monitoring equipment in each neighborhood. Locations were chosen to be as inconspicuous as possible but free from trees or structures that could affect air flow. We used a tapered element oscillating microbalance ambient particulate monitor Series 1400a with a Series 8500 filter dynamics measurement system (Rupprecht and Patashnick Co, Inc., East Greenbush, NY) to record hourly values of PM_{10} and semivolatile PM_{10}. Semivolatile particles are composed of compounds that simultaneously have meaningful concentrations in both vapor and condensed phases. PM_{10} values were updated every 6 min. An MDA Scientific single point monitor (Zellweger Analytics, Inc., North America, Lincolnshire, IL) provided concentrations of H_2S (parts per billion) averaged over 15-min intervals. Temperature, humidity, wind speed, and wind direction were recorded every 10 min with a Vantage Pro Weather Station (Davis Instruments, Hayward, CA), and every 30 min with a Young Model 05103VM-42 Wind Monitor (R.M. Young Company, Traverse City, MI). The Davis wind speed data were more complete, but the instrument was less sensitive, with values about 2 mi/hr (mph) lower than the Young monitor. To fill in missing data from each machine, values from the two machines were collectively categorized as low (≤ 0.57 mph), medium (0.58–6.75 mph), or high (> 6.75 mph). In four communities, data were missing for both weather instruments for some periods. In these cases, which comprise about three percent of total records, data were obtained from the nearest airport weather station, which was about 4.5 mi away for three communities and 18.5 mi away in one.

In each neighborhood a local "community monitor" was shown how to check the operation status of the monitoring equipment and was asked to call research staff on a toll-free line to report any outage or error message. In 12 neighborhoods a study participant served in this capacity.

We calculated the number of swine CAFOs within 2 mi of the monitoring platform using latitude and longitude coordinates derived from online satellite imagery and operating permits issued by the North Carolina Division of Water Quality (Raleigh, NC). Although we used 1.5 mi as the criterion for study elgibility, we counted operations within 2 mi because *a*) odor reports are made from that far away; *b*) that distance has been used in previous research (Thu et al. 1997; Wing and Wolf 2000); and *c*) excess wheezing symptoms have been reported as far as 3 mi from swine CAFOs (Mirabelli et al. 2006). Coordinates for the monitoring trailer and each participant's home were determined using a handheld global positioning system device.

Following input and approval from the Community Research Advisory Board of the Concerned Citizens of Tillery (Tillery, NC) the study protocol and survey instruments were approved by the University of North Carolina's Institutional Review Board for research involving human subjects, which follows national and international standards. All participants gave informed consent. We obtained a Certificate of Confidentiality from the National Institutes of Health because of legal measures taken by the North Carolina Pork Council to obtain identifiable participant information from a prior study (Wing 2002).

Statistical analysis. We evaluated relationships between environmental measurements and twice-daily odor by stratification, standard linear regression, and linear mixed models. We chose the measure of twice-daily odor for these analyses because these odor ratings were provided in real time and at preselected periods, and therefore should be less susceptible to recall bias than ratings of hourly odor since the previous diary entry. The sample sizes for these analyses varied based on the numbers of missing values for environmental measurements. Although hog-odor ratings were highly right-skewed, the number of observations was adequate to produce normal sampling distributions for the regression coefficients (Lumley et al. 2002); therefore, untransformed odor was considered as a continuous dependent variable in our linear regression models. Hourly average H_2S, temperature, humidity, and wind speed for hours centered at the time of sitting outside were considered as predictors of odor. We considered H_2S levels for hours when all measurements were below the detection limit of 2 ppb to be zero.

Mixed models with twice-daily odor as the dependent variable and environmental measures as independent variables were fit using the SAS MIXED procedure (SAS Institute Inc., Cary, NC) to account for variance within people, between people, and between neighborhoods. We compared Akaike information criterion (AIC) statistics for fixed-slope and random-slope models and chose models with lower AIC statistics for presentation. We fit models with intercepts when the only predictor of odor is coded as an indicator variable, providing a test of the difference between the omitted category and the other category or categories. For models with the interaction of a variable coded as continuous and one coded as an indicator, we fit models with no intercept to provide an estimate of the effect of the continuous variable, its SE, and a test of difference from zero, at each level of the indicator variable.

We used mixed logistic regression for analyses of activity limitation as the dependent variable. Average hourly outdoor odor since the previous diary entry was the independent variable. Models were fitted using the SAS GLIMMIX procedure. Random intercepts and fixed effects of average odor ratings of 1 to < 2, 2 to < 3, 3 to < 5, and ≥ 5 compared with no odor were estimated as predictors of activity limitation due to odor, coded as a 0/1 variable. A model was also fit with average hourly odor as a continuous variable.

SEs of regression coefficients are presented as measures of precision in order to reduce the probabilistic interpretations implied by the use of confidence intervals. For the same reason, we assessed contributions of predictors to the fit of models by *t*-tests instead of *p*-values because this is not a randomized study (Greenland 1990).

Results

Neighborhood and participant characteristics. A total of 102 volunteers from 16 neighborhoods enrolled in the study. One person who had difficulty with the study protocol was excluded from analyses. Analyses here include 84 people who collected data for 2 weeks, 15 (from three neighborhoods) who chose to continue an additional 4–7 days, and 2 who stopped before 2 weeks. Sixty-six women and 35 men participated. Age ranged from 19 to 89 years, with a mean age of 53. Eighty-four participants identified themselves as black, 15 as white, one as black/Native American, and one as Latino.

Characteristics of study neighborhoods, labeled A–P, are given in Table 1. Two neighborhoods had one swine CAFO within 2 mi of the monitoring trailer, and six neighborhoods had ≥ 10 within 2 mi. Approximately two-thirds of participants lived in neighborhoods within 2 mi of ≥ 5 swine CAFOs. In nine neighborhoods, participants reported outdoor swine odor on more than half the study days. Mean temperature on study days ranged from 47°F in neighborhood A to 82°F in neighborhood K; no neighborhoods participated during January. Mean H_2S was 0.004 ppb in neighborhood E, where 99.8% of readings were below the detection limit (2 ppb). Neighborhoods O and C had the highest mean values, 1.02 and 1.48 ppb, respectively, and the highest values recorded in neighborhood O were at the upper limit of detection, 90 ppb. Average PM_{10} varied from 10.8 μg/m^3 in neighborhood A to 28.7 μg/m^3 in neighborhoods C and E, whereas semivolatile PM_{10} was highest (9.2 μg/m^3) in neighborhood O and lowest in H (–3.2 μg/m^3), indicating the high degree of measurement error when using the microbalance to characterize semivolatile particle levels over short time periods.

Frequency, magnitude, and duration of odor episodes. We calculated the average daily odor that participants reported following the twice-daily preselected 10-min periods of sitting outdoors, as well as the average hourly outdoor odor reported each day. Study participants collected data on 1,495 days, although twice-daily odor was missing for 39 of these days. Results for the 1,456 days with twice-daily odor information are reported here (Table 2). The average twice-daily odor was zero for 563 days (38.7%), and > 5 on 51 days (3.5%). Average hourly outdoor odor was zero for 591 days (40.6%) and > 5 on 33 days (2.3%). Average twice-daily odor was zero on fewer days than average hourly odor. This is possible because participants could report nonzero odor during twice-daily times sitting outdoors when there was no odor at other times during the hour.

Reported hourly outdoor odor was highest in the mornings and evenings and lowest in the middle of the day and night (Figure 1). Morning odor was highest around 0300 hours (mean = 1.7) when 12.2% of ratings were ≥ 5. Mean hourly odor was 2.1 at 2000 hours, when 19.2% of odor ratings were five or greater.

Based on hourly outdoor odor ratings, participants reported 1,655 odor episodes (Table 3). The duration of an episode is the number of consecutive hours that swine odor was reported to be above zero. The majority of episodes (62.1%) lasted 1 hr, whereas 9 episodes (0.5%) lasted ≥ 9 hr. Average odor was < 2 for about 39% and > 5 for about 16% of odor episodes lasting 1 or 2 hr. Average strength was ≥ 5 for > 21% of odor episodes of ≥ 3 hr.

Hog odor was reported inside homes on 185 of 1,456 person-days of follow-up (12.5%). Five hundred episodes of indoor hourly odor were reported, of which 233 (46.6%) lasted 1 hr, 179 (35.8%) lasted 2–3 hr, and 88 (17.6%) lasted ≥ 4 hr. Three of the 1-hr indoor odor episodes, rated 3, 6 and 8, were reported in the middle of time periods when consistent sleep was indicated.

Butanol odor sensitivity threshold was estimated for 98 participants, of whom 39 had a threshold of 10 or 20 ppm (Table 4). Most odor ratings were provided by people with butanol detection thresholds between 10 and 160 ppm. Average reported odor declined with sensitivity from 20 to 160 ppm. Among the 12 participants with odor thresholds of ≥ 320 there was not a clear relationship between odor sensitivity and average odor.

Environmental correlates of odor. Analyses of environmental correlates were based on the

Table 2. Daily averages of twice-daily and hourly outdoor odor ratings (scale of 0–8).

Mean odor rating	Twice-daily odor [no.(%)]	Hourly outdoor odor [no. (%)]
0	563 (38.7)	591 (40.6)
> 0 to < 2	541 (37.2)	581 (39.9)
> 2 to < 5	301 (20.7)	251 (17.2)
≥ 5	51 (3.5)	33 (2.3)
Total	1,456 (100.0)	1,456 (100.0)

Table 1. Characteristics of neighborhoods and CAFOs within 2 mi of the monitoring platform.

Site	Swine CAFOs (no.)	Participants (no.)	Mean 10-min odor	Days with any odor outdoors (%)	Days with any odor indoors (%)	Mean temp (F)	Mean H_2S (ppb)	H_2S values < 2 ppb (%)	Highest H_2S (ppb)[a]	Mean PM_{10} (μg/m^3)	Mean semivolatile PM_{10} (μg/m^3)
A	1	7	0.4	26	2	47	0.01	99.7	4	10.8	1.1
B	1	6	0.7	48	10	50	0.09	97.0	9	13.6	1.8
C	3	5	1.4	70	14	60	1.48	77.1	28	28.7	2.7
D	3	6	0.8	68	9	59	0.41	90.7	20	13.7	1.4
E	4	7	0.5	20	15	77	> 0.00	99.8	2	28.7	5.9
F	4	4	2.7	95	46	77	0.15	94.2	10	28.4	3.9
G	5	4	0.6	41	2	51	0.07	96.7	3	17.5	5.0
H	9	6	1.0	45	9	63	0.02	98.9	3	16.8	–3.2
I	9	9	2.9	88	23	80	0.40	90.9	20	27.0	7.5
J	9	4	1.9	63	15	79	0.40	91.2	52	21.7	3.5
K	10	8	1.3	73	12	82	0.28	93.3	21	22.8	8.6
L	12	7	0.8	43	3	71	0.05	97.6	4	23.0	4.6
M	12	10	2.1	73	11	75	0.05	98.6	27	17.1	1.6
N	15	5	0.9	49	13	59	0.01	99.5	4	27.3	4.6
O	15	5	1.8	68	26	77	1.02	91.1	90	18.7	9.2
P	16	8	1.2	66	10	59	0.08	97.3	9	19.1	6.5

temp, temperature.
[a]Based on 15-min average values.

twice-daily odor ratings reported at preselected times of day when participants sat outdoors for 10 min. Table 5 provides results of bivariate simple linear regression models for each environmental variable as a predictor of 10-min odor ratings. Odor ratings increased 0.26 ± 0.02 (mean ± SE) for every 10°F increase in temperature; the *t*-test value is large (11.65). Odor ratings increased 0.17 ± 0.02 for every 1-ppb increase in H_2S, 0.04 ± 0.02 for a 10-µg/m^3 increment in PM_{10}, 0.03 ± 0.01 per 1 µg/m^3 of semivolatile PM_{10}, and 0.06 ± 0.02 for a 10% increase in relative humidity. Average odor at moderate wind speeds was 1.02. Compared with moderate wind speeds, odor was higher by 0.43 ± 0.08 at low wind speeds and higher by 0.72 ± 0.15 at high wind speeds.

Temperature and semivolatile PM_{10} showed little association with 10-min odor ratings as main effects in mixed models (data not shown). Table 6 presents effect parameters from mixed models with other environmental variables. The relationship between H_2S and odor was best fit with a random-intercept, random-slope model, in which odor increased 0.15 ± 0.05 (mean ± SE) for every 1-ppb increase in H_2S (*t*-value for H_2S = 3.10).

Because there is a strong main effect for H_2S, we considered odor sensitivity as a modifier of its association with odor. H_2S was positively related to odor among participants with detection thresholds of ≤ 160 ppm (0.17 ± 0.06/1 ppb, mean ± SE), but not among participants with thresholds of ≥ 320 ppm (0.02 ± 0.14/1 ppb).

The relationship between wind speed and odor was adequately fit with a random-intercept, fixed-slope model. Parameters for low and high wind speeds were estimated in mixed models with medium wind speed as the referent (Table 6). Average odor was lowest at medium wind speed (1.23 ± 0.20, mean ± SE). Compared with the odor at medium wind speed, odor was higher by 0.18 ± 0.07 units at low wind speeds and by 0.38 ± 0.13 units at high wind speeds.

Relationships between odor, H_2S, and PM_{10} depended on wind speed (Table 6). A mixed model with fixed effects for wind speed and random effects for H_2S showed that H_2S and odor were not associated at medium wind speed (–0.09 ± 0.10/1 ppb, mean ± SE). At low wind speeds, odor increased 0.28 ± 0.11/1 ppb (t = 2.49), and at high wind speed there was an increase of 0.77 ± 0.44/1 ppb (t = 1.75). In contrast, PM_{10} was associated with odor at high wind speeds (0.45 ± 0.14/10 µg/m^3; t = 3.14), but not at low or medium wind speeds.

Activity limitation. On 118 occasions 34 participants reported that they cancelled or changed an activity because of hog odor. Typical changes included closing windows, avoiding sitting in the yard and socializing with friends, cancelling plans to barbecue, not putting clothes out to dry, declining exercise via outdoor walks, not putting up Christmas lights, not being able to garden or mow the lawn, not washing the car, or not being able to sit on the porch. One participant reported on two occasions that odor made it difficult to sleep. Whereas in other records this participant reported 6–8 hr of sleep during the previous night, on these two occasions he or she indicated having slept either 0 or 4 hr. The common theme in these disruptions was the adverse impact of odor on people's social and

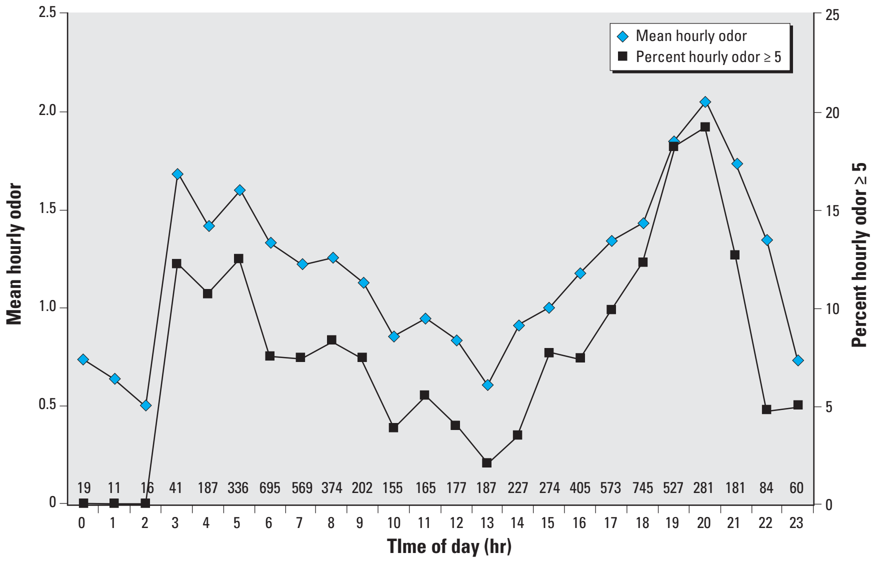

Figure 1. Time of day and odor. Numbers above the *x*-axis indicate the number of hourly ratings for that time point.

Table 3. Duration and strength of reported outdoor odor episodes.

	Duration of hourly outdoor odor episode (hr)					
Mean odor	1 [no.(%)]	2 [no.(%)]	3 [no.(%)]	4–8 [no.(%)]	≥ 9 [no.(%)]	Total
1 to < 2	398 (38.8)	126 (38.5)	30 (18.9)	29 (21.8)	3 (33.3)	586 (35.4)
2 to < 5	462 (45.0)	152 (46.5)	89 (56.0)	76 (57.1)	4 (44.4)	783 (47.3)
≥ 5	167 (16.3)	49 (15.0)	40 (25.2)	28 (21.1)	2 (22.2)	286 (17.3)
Total	1,027 (100.0)	327 (100.0)	159 (100.0)	133 (100.0)	9 (100.0)	1,655 (100.0)

Table 4. Butanol odor sensitivity threshold and mean twice-daily odor.

Butanol (ppm)	No. of participants	No. of twice-daily odor ratings	Mean odor
10	18	503	1.51
20	21	575	1.64
40	15	405	1.32
80	14	396	1.08
160	17	479	0.85
320	4	97	1.39
640	5	125	1.25
1,280	1	20	1.55
2,560	1	27	4.89
5,120	1	28	2.07
20,480	1	28	1.00

Table 5. Simple linear regression coefficients for environmental predictors of odor.

	No. of records	Coefficient	SE	*t*-Value
Temperature (× 10)	2,772	0.26	0.02	11.42
H_2S (ppb)	2,701	0.17	0.02	8.73
PM_{10} (10 µg/m^3)	2,005	0.03	0.02	1.89
Semivolatile PM_{10} (µg/m^3)	2,005	0.03	0.01	2.90
Humidity (10%)	2,772	0.05	0.02	2.91
Low wind	1,617	0.43	0.08	5.73
Medium wind (intercept)	972	1.02	0.06	16.96
High wind	183	0.73	0.15	4.87

personal space. There was an association between activity change and average outdoor odor intensity during the 12 hr prior to a diary record, with odor grouped into several levels (Table 7). Participants noted changes in activity due to odor from 1.4% of occasions when average odor was < 1.0 up to 16.2% when average odor was ≥ 5.0. Estimates from logistic mixed models with random intercepts and a fixed slope for odor show a similar relationship; all model coefficients are substantially larger than their SEs, and *t*-values are large. A separate model was estimated for odor as a continuous variable; the log odds ratio of activity change for a one-unit increase in odor is 0.48 ± 0.07, a 62% increase in the odds of activity change per odor unit ($t = 7.17$).

Discussion

In the present study 101 participants from 16 neighborhoods in eastern North Carolina reported on the strength of hog odor inside and outside their homes for approximately 2 weeks while temperature, humidity, wind speed, H_2S, and PM_{10} were monitored nearby. One to 16 swine CAFOs were located within 2 mi of the monitoring platform in each neighborhood. Odor was reported outside on more than half the study days in 9 neighborhoods. Odor ratings made during 10-min periods of sitting outside twice a day were associated with weather conditions, H_2S, and PM_{10}. One-third of participants reported ceasing or changing their activities due to malodor, and the intensity of odors reported between diary entries was strongly associated with these reports. This study indicates that malodor from swine operations is commonly present in these communities and that the odors reported by neighbors are related to objective environmental measurements.

Neighborhoods were included in the study if at least several members were interested in participating in a 2-week study that required a 3-hr training session and a twice-daily routine of reporting and measurement. Neither the neighborhoods nor participants are a representative or systematic sample of the region. We relied on local knowledge to select neighborhoods where hog odor had been reported to community organizers and where individuals might be interested in participating. However, there are > 2,000 swine CAFOs in the region, and we had no way to identify those CAFOs with higher releases of odorant chemicals. Although it is unlikely that neighborhoods with the highest exposures were included in this study, neighborhoods with no odor problems, if they exist, would not have been included either. Pollution levels and odor strength in this study may also have been affected by actions taken by operators of swine CAFOs near the study sites; participants in several neighborhoods reported cessation or relocation of hog waste sprayers, as well as reduced odor, during their period of study participation.

Other analyses indicated that the completeness and consistency of data in this study were high (Schinasi 2007). Participants reported twice-daily odor ratings in 94% of 2,949 total journal entries and at least one such rating on 97% of 1,495 study days. On the 1,456 study days with at least one twice-daily odor rating, the mean and median percentages of hours of the day for which hourly odor ratings were provided were 96% and 100%, respectively. On 95% of study days, participants reported information on whether hog odor had altered their daily activities.

We evaluated the hypothetical possibility that, due to their access to the H_2S monitor, odor ratings of 12 study participants who were asked to check for malfunctions with the environmental monitoring equipment could have been influenced by the value on the display screen; in this case the relationship between H_2S and odor might be overestimated. We refit the random-intercept, random-slope model for H_2S and odor excluding these 12 participants; the β coefficient and its SE rounded to the same values reported in Table 6.

Although the structured reporting of odor by neighbors of swine CAFOs is a strength of our study, the frequency, duration, and intensity of reported hog odor episodes must be interpreted in the context of participants' daily activity patterns. Participants reported being indoors at home 30.0%, outdoors at home 17.1%, away from home 25.5%, and sleeping 27.4% of hours in the study. The large proportion of time spent indoors and away from home limits information on outdoor odor episodes. The duration of outdoor odor episodes is also truncated by going indoors or away from home to avoid odor; this may contribute to the shorter duration of reported outdoor hourly odor episodes (62.1% lasted 1 hr) compared with indoor hourly odor (46.6% lasted 1 hr).

With the exception of PM_{10} in higher wind conditions, temperature, PM_{10}, and semivolatile PM_{10} were correlated with hog odor ratings only if the within-person, between-person, and between-neighborhood structure of the data was ignored. This might reflect the lack of seasonal variation of these variables within neighborhoods sampled for only about 2 weeks, which is a limitation of the study design. H_2S, in contrast, was strongly related to odor in mixed models. Unlike the weather variables, H_2S levels varied markedly within neighborhoods. In a recent chamber experiment, naïve volunteers exposed to swine CAFO air with a 24 ppb concentration of H_2S reported an average odor of 5.29 on a 0–8 scale (Schiffman et al. 2005). The predicted odor at 24 ppb in the present study, based on the linear regression function from Table 4 [odor = 1.25 + 0.17 × H_2S (ppb)] produces a similar value of 5.33.

In theory, a stronger relationship between odor ratings and the concentration of odorant compounds should have been observed among people with a better sense of smell. We considered butanol detection threshold as a modifier of the H_2S effect because, unlike PM_{10}, it was strongly associated with odor even without taking into account the modifying effect of wind speed. The observation that this association was restricted to people with detection thresholds < 320 ppm suggests that this simple threshold test distinguishes a subgroup of participants (87.8%) who are more responsive to H_2S.

The microbalance produced many negative values for semivolatile PM_{10}, indicating large measurement error relative to the semivolatile

Table 6. Mixed-model coefficients for environmental predictors of odor.

	Effect	SE	*t*-Value
Wind speed[a,b]			
Low	0.18	0.07	2.62
Medium (intercept)	1.23	0.20	6.03
High	0.38	0.13	2.91
Relative humidity ≥ 50%	0.29	0.11	2.59
H_2S (ppb)[c]	0.15	0.05	3.10
H_2S × wind speed[d]			
Low	0.28	0.11	2.49
Medium	–0.09	0.10	–0.83
High	0.77	0.44	1.75
PM_{10} (10 μg/m^3) × wind speed[e]			
Low	–0.01	0.05	–0.23
Medium	0.00	0.02	0.25
High	0.45	0.14	3.14

[a]Random-intercept, fixed-slope model. [b]Low, ≤ 0.57 mph; 0.57 < medium ≤ 6.75; high, > 6.75. [c]Random intercepts, random slopes. [d]Random intercept, random slope for H_2S, random intecept, fixed slope for wind. [e]Random intercept, fixed slope for wind and PM_{10}.

Table 7. Reports of change in activities due to odor in relation to average odor during the previous 12 hr.

12-hr average	No. of changes in activity reports	Percentage of times with change in activity	Rate ratio	$\log_e$ odds ratio[a]	SE	*t*-Value
Odor < 1	22	1.4	1.0	Referent	—	—
1 ≤ odor < 2	23	5.1	3.6	1.32	0.38	3.46
2 ≤ odor < 3	19	7.1	5.0	1.56	0.40	3.93
3 ≤ odor < 5	30	11.0	7.7	2.12	0.39	5.46
Odor ≥ 5	24	16.2	11.3	2.78	0.43	6.39

[a]From mixed model with random intercepts and fixed slope for odor terms.

particle signal. This reduced the power of the study to detect associations between reported odor and semivolatile compounds in particle phase, including ammonia, an important odorant chemical emitted by swine CAFOs (Lim et al. 2003; Reynolds et al. 1997; Wilson and Serre 2007). We did not have the capacity to directly measure ammonia or other odorant compounds for this study.

The presence of air pollution from swine CAFOs in neighboring communities depends on wind direction and speed. We did not evaluate wind direction because there were at least several CAFOs in different directions near most neighborhoods in the study. Wind speed was related to odor and was also a modifier of relationships between air pollution levels and the strength of odors reported by neighbors. Although odor was highest at high wind speeds, mean H_2S levels were lowest at high wind speeds (0.05 ppb) compared with medium (0.09 ppb) and low (0.45 ppb) wind speeds. H_2S was strongly related to odor at low wind speeds (0.28 ± 0.11/1 ppb). Although the point estimate of the odor–H_2S relationship at high wind speeds was very large (0.77), its SE was also large (0.44), reflecting the limited range of H_2S values and smaller sample size at higher wind speeds.

In contrast, PM_{10} was related to odor in mixed models only during periods of higher wind speed. This observation is consistent with the greater capacity of stronger winds to transport PM, and provides evidence that organic dusts from swine CAFOs may be inhaled by CAFO neighbors during higher wind conditions. Although PM_{10} is associated with a variety of health outcomes, most studies have been conducted among populations where the composition of PM is largely affected by combustion by-products and urban dusts. Although PM from animal dander, dried feces, feed, pharmaceuticals, and endotoxin is known to affect occupational health of workers in swine confinement buildings (Donham 1990, 1993; Donham et al. 1995, 2000), its effect at lower levels and among nonworker populations is poorly understood.

Among the 98 participants who answered questions about residential history, 76 grew up on farms where they had experience with animal odors, and 82 had lived in their homes for > 5 years. Thus, adaptation and loss of sensitivity to malodors from swine operations could have occurred. On the other hand, the study protocol prompted participants to pay attention to swine odors, thus, physiologic adaptation or reduced attention to odor as a means of coping may have been offset by the odor-reporting protocol. In considering the effects of odor, it is important to note that adaptation occurs most readily when there is little variation in the concentration of odorant chemicals, whereas swine odors are transient. Like other environmental agents that act as stressors, unpredictable acute odor episodes may cause more of a stress response in susceptible persons than nonepisodic stressors.

The health significance of malodorous compounds is due, in part, to diseases related to pollutants such as PM that would occur even among persons with no sense of smell. However, malodor also should be considered in the context of scientific interest in end points that are not specific diseases. For example, biological markers of exposure to or effects of toxicants, genetic markers of susceptibility, and physiologic states associated with increased risk of disease are widely recognized as relevant to understanding and improving environmental health, even though they are not specific diseases. Similarly, environmental malodor is an important subject for inquiry, not only because it may be involved in causation of specific diseases but because of its potential to affect health, considered as not merely the absence of disease, but as a state of physical, mental, and social well-being (World Health Organization 2002). Environmental malodors may be markers of agents that can produce inflammatory, immunologic, infectious, or toxicologic responses; additionally, they may affect physical, mental, and social well-being due to their psychological and cultural meaning (Schiffman et al. 2000). Odors that are viewed as unpleasant, embarrassing, or sickening may interfere with mood, beneficial uses of property, and social activities that are central to quality of life.

We found that average odor over a 12-hr period relates strongly to changes in activities because of hog odor. Both reports of activity limitations and the three reported episodes of indoor odor that occurred during the middle of time periods of sleep suggest that odor interrupted participants' sleep in the middle of the night. Other studies have shown that the odor of feces and urine from liquid waste management systems can negatively impact neighbors' quality of life. Among a subsample of participants in the present study, odor was found to be related to levels of stress reported in daily diaries (Horton 2007). However, numerical relationships between hog odor and disrupted activity are insufficient to capture the full impacts of quality of life disruptions. Ethnographic interviews conducted with a subsample of study participants demonstrate that malodor, when present, limited many daily physical and social activities that have been shown to reduce stress and promote health (Tajik et al. 2008). Even when odor is not present, anticipation of the potential impact of irregular and unpredictable odor events may create stress and anxiety about daily routines and about social events that could cause embarrassment if odor occurs when relatives, friends, or out-of-town guests are present (Tajik et al. 2008).

Previous studies indicate that North Carolina swine CAFOs are located disproportionately in low-income communities of color (Edwards and Ladd 2000; Ladd and Edwards 2000; Wing et al. 2000). These communities may be more adversely affected by CAFOs because of their limited resources, higher disease rates, poor food supplies, poor housing, and unprotected sources of groundwater for drinking. Lower levels of formal schooling and less access to legal and political resources make it more difficult for such communities to bring about more protective environmental policies and enforcement. The present study adds to a growing body of literature suggesting that malodor from swine CAFOs, and the physical and chemical agents with which it is associated, have the potential to negatively impact public health, especially in communities that are already vulnerable (Donham et al. 2007).

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Exhibit 7 to the
Declaration of Professor Steven B. Wing, Ph.D.

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The Effect of Environmental Odors Emanating From Commercial Swine Operations on the Mood of Nearby Residents

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ABSTRACT: The effect of environmental odors emanating from large-scale hog operations on the mood of nearby residents was determined using the POMS (Profile of Mood States). The scores for six POMS factors and the TMD (total mood disturbance score) for 44 experimental subjects were compared to those of 44 control subjects who were matched according to gender, race, age, and years of education. The results indicated a significant difference between control and experimental subjects for all six POMS factors and the TMD. Persons living near the intensive swine operations who experienced the odors reported significantly more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects as measured by the POMS. Persons exposed to the odors also had more total mood disturbance than controls as determined by their ratings on the POMS. Both innate physiological responses and learned responses may play a role in the impairment of mood found here.

KEY WORDS: Odors, Mood, Pollution, Swine, Psychological effects, Brain-immune connections.

INTRODUCTION

Odors have always been associated with livestock and poultry production [24,55,72,78,79,86,88]. However, odors have recently become a major challenge for the livestock industry due to the present trend toward intensive livestock operations in which large numbers of animals are confined on small areas of land [8,19,51,69,120,122–124,127]. Environmental odors can have a considerable impact upon a population's general well-being, affecting both physiological and psychological status [93,103,128]. Miner [70] concluded that unpleasant odors can affect well-being by "eliciting unpleasant sensations, triggering possible harmful reflexes, modifying olfactory function and other physiological reactions." He also reported that annoyance and depression can result from exposure to unpleasant odors along with nausea, vomiting, headache, shallow breathing, coughing, sleep disturbances, and loss of appetite. Odorous compounds associated with livestock production that are at low concentrations but above odor thresholds are still likely to generate complaints [18,52].

Neutra et al. [77] studied people living near hazardous waste sites, and found that those complaining of odors had a higher number of symptoms than those who did not complain, regardless of proximity to the site. Shusterman [103] reviewed several studies [e.g., 4,37,47,95–97] in which there was a direct relationship between nontoxicological odors and symptomatology. In a variety of settings (municipal, agricultural, and industrial) where airborne toxicants were negligible and odors had been complained about, there was a strong relationship between reported symptoms and odor exposure.

The sources of the odors from swine operations include ventilation air released from swine buildings, waste storage and handling systems including lagoons, and land application of manure to fertilize fields [15]. The odors are produced by a mixture of fresh and decomposing feces, urine, and spilled feed. The more objectionable odors appear to result from anaerobic microbial decomposition of the feces [90]. A broad range of compounds has been identified in livestock manure including volatile organic acids, alcohols, aldehydes, amines, fixed gases, carbonyls, esters, sulfides, disulfides, mercaptans, and nitrogen heterocycles [30,70,71,73,104]. It is likely that the mixture of compounds rather than a single component contributes to the mood changes measured here.

A variety of techniques for reducing odor have been evaluated, but overall the results have been disappointing [123]. Aerobic treatment has been found to be the most effective method to date for deodorizing pig slurry [2,9,11,54,105–107,127]. Odorous compounds can be carried in a plume, and the concentration of these compounds in the plume may not be significantly reduced at distances of 750–1500 feet or more downwind from a source [36]. Dispersion models have been developed to predict the peak and mean concentrations of odors and environmental air pollutants at various distances from the source [20,36,46,80], and complaint patterns at a variety of distances from an odor source have been studied [21].

The purpose of the present study was to use a well-standardized scale to quantify objectively the moods of people living near large-scale hog operations who are exposed to odors. The Profile

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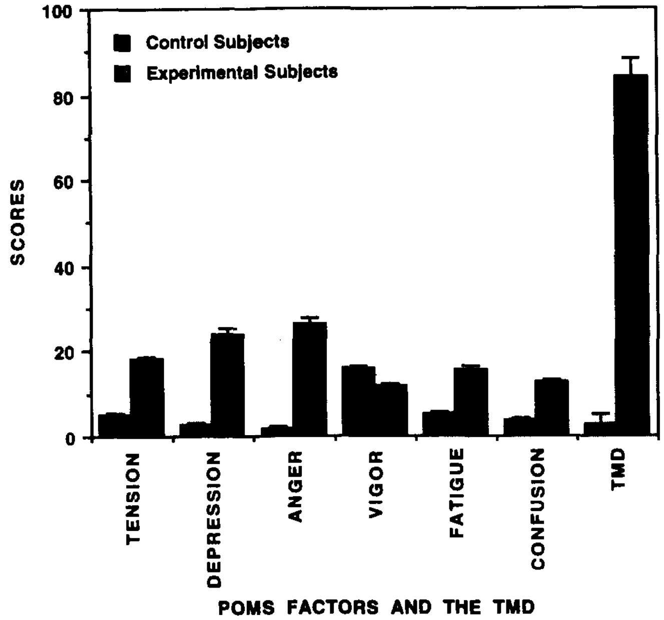

FIG. 1. Mean POMS scores of each factor and the total mood disturbance score (TMD) for experimental and control subjects.

of Mood States questionnaire [65,66] was used to assess mood in persons living near swine operations and in control subjects. This scale has been used extensively in many situations including previous studies that evaluated the effect of pleasant odors on mood [98,99]. The study of mood in persons exposed to odors is important because negative mood has been found to play a role in immunity [16,81,111,125] and can potentially affect subsequent disease.

METHOD

Subjects

Forty-four experimental (persons living near hog operations) and 44 control subjects participated in the study; all of the subjects were residents of North Carolina. The subjects in the two groups (control and experimental) were matched according to gender, race, age, and years of education. Twenty-six subjects in each group were female, and 18 subjects were male. The mean age of the experimental group was 52.0 ± 13.4 years, and the mean age of the control group was 51.7 ± 8.3 years. The experimental group had an average of 12.8 ± 3.3 years of education, and the control group had an average of 13.0 ± 3.1 years of education. The majority of subjects in both groups were employed as skilled laborers. The groups were also matched for the number of chronic illnesses that they had experienced; 14 subjects in each group suffered from allergies. The experimental group lived an average of 5.3 ± 6.5 years near hog operations, with a maximum of 27 years and a minimum of 8 months.

Materials

Subjects in both groups signed a consent form and filled out a general information questionnaire that asked demographic, medical, and dietary information. Mood ratings were obtained from all subjects by filling out Profile of Mood States questionnaires (POMS). The POMS was chosen to measure the impact of the hog odors on mood because it has been shown to be sensitive to transient mood shifts [65,66]. There are 65 adjectives/feelings on the POMS, most of which may be grouped into one of six factors: tension/anxiety, depression/dejection, anger/hostility, vigor/activity, fatigue/inertia, and confusion/bewilderment. Each feeling is rated on a scale from 0 (not at all) to 4 (extremely). The feelings for each factor were added together, according to the POMS manual, to get a total score for that factor. The totals for each factor were then added together, with the vigor/activity factor weighted negatively, to derive a total mood disturbance score (TMD).

Procedure

At the beginning of the study, all subjects filled out the consent form as well as the general information questionnaire. Experimental subjects were asked to complete one POMS questionnaire per day on 4 days when the hog odor could be smelled. The 4 days did not have to be consecutive, and subjects had as long as needed to complete all four POMS questionnaires. Control subjects were asked to complete one POMS per day for 2 days. All subjects were asked to complete the POMS based upon how they recently had been feeling, including at that particular time.

RESULTS

Figure 1 shows the means and standard errors for the experimental group vs. the control group for all POMS factors and the TMD. An analysis of variance was performed to determine if there were any main effects or interactions between group (control or experimental) and gender for each POMS factor and the TMD. Subjects were nested within group and gender. Table 1 gives the results of the analysis. There was a significant difference (at $p < 0.0001$ level) between the control group and the experimental group for all of the POMS factors as well as the TMD. The experimental group had significantly worse scores than the control group for every factor and the TMD. There was a significant main effect of gender for the anger factor, $p < 0.01$, and a significant gender × group interaction for the confusion factor, $p < 0.005$. Males had significantly higher (worse) anger scores than the females. For the confusion factor, scores for experimental males were significantly higher than those for experimental females and control males and females; scores for ex-

TABLE 1

RESULTS OF THE ANALYSIS OF VARIANCE

Effect	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Total Mood Disturbance Score
Group	*	*	*	*	*	*	*
Gender			*				
Group × gender						*	
Subject (group, gender)	*	*	*	*	*	*	*

* Significant at $\alpha = 0.05$ level.

perimental females were significantly higher than those of control males and females. Only scores for control males and control females were not significantly different from each other.

DISCUSSION

The main finding of this study is that persons living near the swine operations who experienced the odors had significantly more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects as measured by the Profile of Mood States (POMS). In addition, persons exposed to the odors also had more total mood disturbance than controls as determined by their ratings on the POMS. These findings are consistent with previous studies in which odors of varying hedonic properties have been found to affect mood [7,32,93,98,99,103,128]. In other settings, odors have also been reported to affect cognitive performance [57,62] and physiological responses including heart rate and electroencephalographic patterns [56,58–61,64].

Possible Causes of Altered Mood

A variety of factors may play a role in the altered mood of residents who are exposed to odors from nearby swine operations. These factors include: a) the unpleasantness of the sensory quality of the odor; b) the intermittent nature of the stimulus; c) learned aversions to the odor; d) potential neural stimulation of immune responses via direct neural connections between odor centers in the brain and lymphoid tissue; e) direct physical effects from molecules in the plume including nasal and respiratory irritation; f) possible chemosensory disorders; and g) unpleasant thoughts associated with the odor.

At moderate to high odor intensities, most persons rate the quality of the odor from the swine operations as unpleasant. The odor is not only perceived while breathing outdoor air but can also be perceived within the homes of nearby residents due to air circulation through open windows and air conditioning systems. The odorant molecules can be absorbed by clothing, curtains, and building materials which act as a sink; the molecules are then released slowly over a period of time from textiles and other materials after the plume has passed the house increasing the temporal exposure to the odor. The intermittent nature of the odors may also be a factor in the mood of persons living near swine operations. Studies of noise have shown that intermittent stimuli produce more arousal and are more likely to affect performance negatively than constant noise [22]. This is due in part to feelings of lack of control over the timing of unwanted transient stimuli. Differences in responses to irregular noise and predictable noise are not only found in humans but in animals as well [27].

Learning (via conditioning) may also play a role in the psychological and physical effects from odors. Conditioned aversions to odors are well-documented in the scientific literature [31,38,44,67,75,119]. Aversive conditioning can occur if environmental odors are associated with an irritant or other toxic chemicals such as pesticides [103]. In addition, conditioned alterations in immune responses using chemosensory (smell and taste) stimuli provide strong evidence for functional relationships between chemosensory centers in the brain and the immune system [1]. Both conditioned immunosuppression and immunoenhancement have been reported using chemosensory stimuli as the conditioned stimulus [1,31,42,43,109,110].

There is a potential for unpleasant odors to influence physical health without involvement of learning or conditioning due to the direct anatomical connections between the olfactory system and the immune system. Brain structures broadly involved in smell [12,35,39,49,82–85,101,112,114–116] can modulate immune responses, especially via the integrated circuitry of the limbic cortex, limbic forebrain, hypothalamus, and brain stem [13,25,26,48,50,76,92,118]. These studies provide an anatomical basis for the possibility that sensory stimulation of the limbic forebrain, hypothalamus, and other odor projection areas of the brain can directly alter immune status. The links between the brain and the immune system are bidirectional [108] so that immune responses can also affect odor centers in the brain [10,94].

Components in the odorous plume may also have direct physical effects on the body. Some of the odorant molecules implicated in malodor from hog farms can cause nasal and respiratory irritation [15,23,29,70,103]. Nasal irritation has been shown to elevate adrenalin [3] which may contribute to feelings of anger and tension. The volatile organic compounds (VOCs) responsible for odors may also be absorbed directly by the body (into the bloodstream and fat stores) via gas exchange in the lungs. Many VOCs that are inhaled into the lungs are known to reach blood and adipose tissue [4,6,53,63,126]. Persons who have absorbed odorants through the lungs can sometimes smell the odor for hours after exposure due to slow release of the odorants from the bloodstream into expired air activating the olfactory receptors. Volatile organic compounds are well known to be eliminated in breath after exposure [89,121], and methods for measuring VOCs in breath have been described [87,89,117]. It is also theoretically possible for some compounds in the plume to be transmitted to the brain via olfactory neurons because a range of agents have been found to reach the brain through the nasal route [28,33,45,74,91,102]. Endotoxin, a component of bacteria, found in the swine house air environment [29], may also be present in the plume. Persons with olfactory dysfunction caused by factors unrelated to swine odor such as concurrent medical conditions, drugs they are taking, or pesticide exposure [100], may find the odor even more objectionable due to their abnormal smell functioning.

Finally, odors may alter mood because they are associated with unpleasant thoughts. Some persons consider the smell from hog farms a taboo odor, which they should not have to endure. For other persons, the odors generate environmental concerns, fear of loss of use and value of property, or a conviction that odors interfere with their enjoyment of life and property. Livestock odors may also be considered inappropriate in certain environments. Odor complaints have been reported to be most frequent among new, large, or recently expanded facilities that are located near existing residences or shopping areas [70,113]. Part of the motivation for odor complaints may be the increased awareness of other environmental agents, such as tobacco smoke, which is malodorous and is considered dangerous to one's health.

Lack of Legislation to Monitor Odor Levels

Odors are not regulated by the Clean Air Act because they are generally regarded as nontoxic [15]. In addition, nonfederal legislation for controlling odors from swine operations is imprecise or lacking in many states. For example, North Carolina Administrative Code Title 15A-02D.0522(c) specifies that "a person shall not cause, allow, or permit any plant to be operated without employing suitable measures for the control of odorous emissions including wet scrubbers, incinerators, or such other devices as approved by the Commission." This regulation is subjective because it gives no provision for either emission standards or ambient air standards. Under this regulation, it appears that as long as a plant has suitable control devices, it is lawful for them to emit offensive odors. In addition, it is unclear what type of operation is to be considered a plant. In contrast, Connecticut's laws on odor emissions set specific standards, as shown in Table

TABLE 2

ACCEPTANCE LIMITS FOR ODORS (FROM 17)

Chemical	ppm by Volume
Acetaldehyde	0.21
Acetic acid	1.0
Acetone	100.0
Acrolein	0.21*
Acrylonitrile	21.4*
Allyl chloride	0.47
Amine, dimethyl	0.047
Amine, monomethyl	0.021
Amine, trimethyl	0.00021
Ammonia	46.8*
Aniline	1.0
Benzene	4.68
Benzyl chloride	0.047
Benzyl sulfide	0.0021
Bromine	0.047
Butyric acid	0.001
Carbon disulfide	0.21
Carbon tetrachloride (chlorination of CS_2)	21.4*
Carbon tetrachloride (chlorination of CH_4)	100.0*
Chloral	0.047
Chlorine	0.314
Dimethylacetamide	46.8*
Dimethylformamide	100.0*
Dimethyl sulfide	0.001
Diphenyl ether	0.1
Diphenyl sulfide	0.0047
Ethanol (synthetic)	10.0
Ethyl acrylate	0.00047
Ethyl mercaptan	0.001
Formaldehyde	1.0
Hydrochloric acid gas	10.0*
Hydrogen sulfide gas	0.00047
Methanol	100.0
Methyl chloride	(above 10 ppm)
Methylene chloride	214.0*
Methyl ethyl ketone	10.0
Methyl isobutyl ketone	0.47
Methyl mercaptan	0.0021
Methyl methacrylate	0.21
Monochlorobenzene	0.21
Monomethylamine	0.021
Nitrobenzene	0.0047
Paracresol	0.001
Paraxylene	0.47
Perchloroethylene	4.68
Phenol	0.047
Phosgene	1.0*
Phosphine	0.021
Pyridine	0.021
Styrene (inhibited)	0.1
Styrene (uninhibited)	0.047
Sulfur dichloride	0.001
Sulfur dioxide	0.47
Toluene (from coke)	4.68
Toluene (from petroleum)	2.14
Toluene diisocyanate	2.14*
Trichloroethylene	21.4

* Exceeds the Threshold Limit Value adopted by the American conference of Industrial Hygienists for 1971.

2 [17]. Similarly, in the Netherlands, regulations are based on accurate records of manure production and bookkeeping, and violations are considered a criminal offense [14].

Regulations need to be established in all 50 states because animal wastes contain high levels of volatile organic compounds that can produce strong odors. The annual production of animal manure in the US in 1987 was estimated at 1.5 billion tons per year, which is enough to apply one ton per acre on each of the 1.9 billion acres of the continental US [14].

Persons exposed to high levels of odor from agricultural sources generally use nuisance laws to protect their rights. However, there are many caveats in nuisance laws that consider a) which party was there first; b) the character of the neighborhood; c) the reasonableness of the use of the land; and d) the nature and degree of the interference [40]. In addition, most states have right-to-farm statutes that supersede nuisance laws in some circumstances [40]. Strong support against nuisance suits involving agriculture is not specific to the United States but is found in the laws of many countries [5]. Suits against agricultural activities based on odor nuisance are harder to prove than those based on water pollution [68]. In addition, nuisance claims fall under state laws, while suits on water pollution are most frequently filed in federal courts.

Conclusion

Odors from swine operations have a significant negative impact on mood of nearby residents. Methods must be found to lower the concentrations of compounds responsible for the odors so that swine operations do not affect the emotional lives of residents in the local vicinities. This may involve legislation that sets standards for odor. In addition, technological solutions must be found to reduce the concentrations of the offending compounds.

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Exhibit 8 to the
Declaration of Professor Steven B. Wing, Ph.D.

Malodor as a Trigger of Stress and Negative Mood in Neighbors of Industrial Hog Operations

Rachel Avery Horton, PhD, Steve Wing, PhD, Stephen W. Marshall, PhD, and Kimberly A. Brownley, PhD

Objectives. We evaluated malodor and air pollutants near industrial hog operations as environmental stressors and negative mood triggers.

Methods. We collected data from 101 nonsmoking adults in 16 neighborhoods within 1.5 miles of at least 1 industrial hog operation in eastern North Carolina. Participants rated malodor intensity, stress, and mood for 2 weeks while air pollutants were monitored.

Results. Reported malodor was associated with stress and 4 mood states; odds ratios (ORs) for a 1-unit change on the 0-to-8 odor scale ranged from 1.31 (95% confidence interval [CI]=1.16, 1.50) to 1.81 (95% CI=1.63, 2.00). ORs for stress and feeling nervous or anxious were 1.18 (95% CI=1.08, 1.30) and 1.12 (95% CI=1.03, 1.22), respectively, for a 1 ppb change in hydrogen sulfide and 1.06 (95% CI=1.00, 1.11) and 1.10 (95% CI=1.03, 1.17), respectively, for a 1 $\mu g/m^3$ change in semivolatile particulate matter less than 10 μm in aerodynamic diameter (PM_{10}).

Conclusions. Hog odor, hydrogen sulfide, and semivolatile PM_{10} are related to stress and negative mood in disproportionately low-income communities near industrial hog operations in eastern North Carolina. Malodor should be considered in studies of health impacts of environmental injustice. (*Am J Public Health.* 2009;99:S610–S615. doi:10.2105/AJPH.2008.148924)

Odor, noise, heat, and crowding are environmental stressors[1] that may affect physical and mental health. Malodor is reported in neighborhoods near hazardous waste facilities, petroleum refineries, certain industrial facilities, and confined animal feeding operations; people in these areas may report sensations of irritation, respiratory problems and other physical health symptoms, interference with activities of daily living, and concerns about chronic diseases and property values.[1–37] Because polluting facilities are disproportionately located in low-income communities and communities of color,[38,39] malodor is an important aspect of environmental injustice that threatens physical, mental, and social well-being.[40]

Several studies have evaluated relationships among malodor, negative mood, and reduced quality of life in neighbors of industrial hog operations. Schiffman et al.[26] found that a small sample of neighbors of industrial hog operations reported more tension, depression, anger, fatigue, and confusion, and less vigor, compared with an unexposed rural sample. Bullers[4] found higher mean scores on a short form of the Center for Epidemiologic Studies Depression Scale (CES-D) in neighbors of industrial hog operations than in control participants (2.24 vs 1.84). Wing and Wolf[36] assessed effects on quality of life, determined by asking how often neighbors of hog operations could open windows or go outside during nice weather. By that metric, neighbors reported greatly reduced quality of life relative to other demographically comparable rural residents.

The Community Health Effects of Industrial Hog Operations (CHEIHO) study was a collaborative community-based participatory research project conducted in the predominantly low-income African American communities of rural eastern North Carolina where industrial hog operations are disproportionately located.[35] The purpose of this study was to evaluate longitudinal relationships among malodor, airborne emissions, stress, and negative mood. We hypothesized that malodor from industrial hog operations is an environmental stressor that may also negatively affect mood.

METHODS

We have previously described the CHEIHO study, including details of its community-based design and its links to education and organizing for environmental justice.[41] Research on health effects in neighbors of industrial hog operations is community-based at its origin. Community-based organizations brought the issue to the attention of researchers at the School of Public Health at the University of North Carolina and have continued as partners in all research that has been conducted. In the CHEIHO study, members of community-based organizations participated as advisors in the study design and design of study instruments. They were integrally involved in the recruitment and training of study participants. Indeed, community organizers were essential to the recruitment and retention of study participants in predominantly African American communities with historic distrust of researchers and research institutions.[42]

Study Participants

Eligible participants in the CHEIHO study were nonsmoking adults who lived within 1.5 miles of at least 1 industrial hog operation and were willing to collect data twice daily for approximately 2 weeks. Between September 2003 and September 2005, participants collected data on odor, stress, mood, physical health symptoms, blood pressure, immune function, and lung function; outcomes analyzed in this study are described in more detail in the paragraphs that follow.

At a central location in each neighborhood, research staff set up a monitoring trailer to collect data on hydrogen sulfide (H_2S; MDA Scientific Single Point Monitor, Honeywell Analytics Inc North America, Lincolnshire, IL), particulate matter less than 10 μm in aerodynamic diameter (PM_{10}) and semivolatile PM_{10} (Tapered Element Oscillating Microbalance Series 1400a Ambient Particulate Monitor with a Series 8500 Filter Dynamics Measurement

System, Thermo Fisher Scientific, Waltham, MA), and weather (Vantage Pro Weather Station, Davis Instruments, Hayward, CA, and Young Model 05103VM-42 Wind Monitor, R.M. Young Company, Traverse City, MI).

Selection of the particular pollutants to be monitored was based on previous work that has documented emissions of both H_2S (a product of the anaerobic decomposition of hog waste) and particulate matter from feed, dried feces, skin cells, hair, and bioaerosols, at confinement buildings and waste lagoons.[6,43] Furthermore, we found that H_2S and PM_{10} were related to reported malodor in the CHEIHO study; H_2S was associated with reported malodor in models that adjusted for the study's longitudinal design, as was PM_{10} during times when wind speed was greater than 6.75 miles per hour.[44]

The average distance from the monitoring platform to the nearest industrial hog operation in each neighborhood was 0.51 miles; the minimum distance to the nearest industrial hog operation was 0.20 miles and the maximum distance to the nearest industrial hog operation was 1.42 miles. In 2 of the 16 neighborhoods, the platform was located within 2 miles of 1 industrial hog operation; in the other 14 neighborhoods, however, the platform was located within 2 miles of at least 3 industrial hog operations (maximum of 16 industrial hog operations). We therefore calculated, for each neighborhood, the average distance between the platform and the industrial hog operations within 2 miles of the monitoring platform. The average distance across all neighborhoods was 1.10 miles, with a range by neighborhood from 0.56 miles to 1.50 miles. In contrast, the average distance between participant households and the monitoring platform across 15 of the 16 neighborhoods was 0.20 miles, with a range by neighborhood from 0.03 miles to 0.36 miles.

In 1 neighborhood, the average distance between participant households and the platform was 0.95 miles. In this and 3 other neighborhoods where participant homes were more geographically dispersed, we deployed additional H_2S monitors at homes farthest from the platform. All of the data on particulate matter, however, were collected at the platform and assigned to all participants in the neighborhood.

Participants attended a 3-hour training session during which they learned to complete the required data collection activities. They selected a morning time and an evening time at which they would collect data (for example, 6:00 AM and 6:00 PM). In addition, participants completed an assessment of coping style using the John Henryism Active Coping scale[45,46] and an assessment of threshold odor sensitivity using butanol standards.[47]

At the preselected, twice-daily times, participants spent 10 minutes outdoors at home and then returned indoors to rate any odor present during that 10-minute period on a 9-point scale ranging from 0 (no odor) to 8 (very strong odor). Hourly average H_2S, PM_{10}, and semivolatile PM_{10} values were calculated for the hour immediately preceding the odor rating. Following the odor rating, they responded to 5 mood state questions: "How do you feel now: (a) stressed or annoyed?, (b) nervous or anxious?, (c) gloomy, blue, or unhappy?, (d) angry, grouchy, or bad-tempered?, (e) confused or unable to concentrate?" They rated these mood questions on a 9-point scale ranging from 0 (not at all) to 8 (extremely). The "stressed or annoyed?" question was an ad-hoc single-item measure,[48,49] and the remaining 4 questions came from the Profile of Mood States instrument,[26,50] specifically, from the Tension–Anxiety, Depression–Dejection, Anger–Hostility, and Confusion–Bewilderment subscales. (The Fatigue–Inertia and Vigor–Activity subscales were not used.)

Statistical Analyses

We used logistic mixed models to evaluate malodor, H_2S, PM_{10}, and semivolatile PM_{10} as predictors of reported stress and negative mood (NLMIXED procedure in SAS version 9.1.3, Cary, NC). We used 2-level (within person and between person) mixed models to take into account the correlated structure of longitudinal data for individuals. The stress and mood variables were recoded as binary; for stressed or annoyed and nervous or anxious, 0 and 1 on the original scale were coded as 0 and 2 to 8 on the original scale were coded as 1. For the remaining 3 mood variables, 0 on the original scale was also coded as 0 and 1 to 8 on the original scale were coded as 1. These coding decisions were based on the distribution of the data such that approximately 90% of the records for each outcome variable were coded as 0 and approximately 10% were coded as 1. We included all predictor variables as linear terms. We conducted all analyses with records for which the ratings of malodor, stress, and mood, and the airborne emissions data, were not missing.

Random intercepts were included in the mixed logistic models to capture the variation between participants in baseline (average) levels of stress and negative mood. Models included the following time-dependent covariates: time of day (morning vs evening), study day (1 to ≥14), and study week (first vs second). For analyses of odor as a predictor of stress and mood, the models also included whether participants reported a cold, flu, or stomach virus at any time during data collection (yes or no). We hypothesized that illness could affect a participant's ability to smell or perception of odor and negative mood. We did not consider time-independent confounders, such as age or gender, because their relationship with exposure and outcome did not vary over time. A sample logistic mixed model follows.

Level 1 (time, within person):

$$(1)\ \mathrm{Logit}\,(\Pr[\mathrm{Stress}_{ij} = 1]) = b_{0j} + b_{1j}(\mathrm{odor}) + b_{2j}(\mathrm{time\ of\ day}),$$

where $\Pr[\mathrm{Stress}_{ij}=1]$ is the probability that stress reported by person j at timepoint i equaled 1, b_{0j} is the person-specific intercept, b_{1j} is the effect of the time-dependent odor rating, and b_{2j} is the effect of time of day (morning vs evening).

Level 2 (between person):

$$(2)\ b_{0j} = \gamma_{00} + \gamma_{01}(\mathit{person}_j) + \mu_{0j};\ \mu_{0j} \sim N(0, \tau_{00}),$$

where b_{0j} is the person-specific intercept, γ_{00} is the mean of the person-specific intercepts (i.e., fixed intercept), $\gamma_{01}(\mathrm{person}_j)$ is the contribution to the overall mean from person j, and μ_{0j} is the residual between-person variation in the intercept.

We also evaluated several potential modifiers. For analyses of H_2S as a predictor of stress and negative mood, we considered modification by wind speed (low [≤0.57 mph], medium [0.58 mph–6.75 mph], and high [>6.75 mph]) because of previous work that suggested modification of the relationship between H_2S and reported malodor by wind speed.[44] Based on previous research,[3,29,30,37] we considered age, dichotomized at the median (≤53.7 years vs >53.7 years), and coping style, dichotomized at the median, (John Henryism Active Coping scale score <52 vs ≥52)[46,47] as potential modifiers of any association between reported odor and stress. We also considered threshold odor sensitivity (low or moderate [<320 ppm] vs high [≥320 ppm]) as a potential modifier of the relationships between odor, stress, and mood to evaluate whether more-sensitive individuals responded differently than less-sensitive ones.

RESULTS

There were 2895 records from 101 individuals in 16 neighborhoods. Complete data on reported odor, stress, and mood were available for 2666 records. Of the 2666 records with complete odor, stress, and mood data from study participants, 78 records were missing data on H_2S and 741 records were missing data on PM_{10} because of monitoring equipment malfunction.

Demographics

Table 1 presents demographic information about study participants. The median age was 53.7 years; age ranged from 19.2 years to 89.5 years. Approximately two thirds of the participants were female, and approximately 85% were African American. Seventy-five percent of participants reported that they grew up around livestock. Six neighborhoods were within 2 miles of 1 to 4 industrial hog operations, 4 were within 2 miles of 5 to 9 industrial hog operations, and 6 were within 2 miles of 10 or more industrial hog operations. Average H_2S values in the 16 neighborhoods ranged from less than 0.01 ppb to 1.5 ppb, and the highest measured H_2S values ranged from 2 ppb to 90 ppb. Average PM_{10} values ranged from 10.8 μg per cubic meter (μg/m^3) to 28.7 μg/m^3, and average semivolatile PM_{10} values ranged from –3.2 μg/m^3 (negative values occurred because of measurement imprecision at very low concentrations) to 9.2 μg/m^3.[44]

TABLE 1—Participant Characteristics: Community Health Effects of Industrial Hog Operations Study, Eastern North Carolina, 2003–2005

	No. of Records	No. of Participants
Age		
>53.7 y	1377	50
≤53.7 y	1289	51
Gender		
Female	1737	66
Male	929	35
Race		
Black	2167	85
Non-Black[a]	499	16
Grew up around livestock		
Yes	1998	76
No	591	22
Missing	77	3
Total	2666	101

[a]Fifteen White participants and 1 Latino participant.

The distribution of twice-daily odor ratings during the preselected 10-minute exposure times is presented in Table 2. Of the 2666 odor ratings recorded after participants spent 10 minutes outdoors, approximately 50% equaled zero. An additional 30% were low (a rating of 1 or 2) on the 9-point scale. Approximately 20% were 3 or higher, and 1% of the data were in each of the 2 highest categories. Most of the ratings of stress and mood state also equaled zero. For "stressed or annoyed," 81% of reports were zero; 87% were zero for "nervous or anxious," 88% for "gloomy, blue, or unhappy," 93% for "angry, grouchy, or bad-tempered," and 95% for "confused or unable to concentrate" (Table 2).

Mixed Models

Table 3 presents parameter estimates, standard errors, *t* values, odds ratios (ORs), and 95% confidence intervals (CIs) for H_2S, PM_{10}, semivolatile PM_{10}, and reported malodor as predictors of binary stress and negative mood. Variables considered as time-dependent confounders produced little change in the magnitude of the parameter estimates for the independent variables. However, we adjusted all models for time of day (morning vs evening) because time is an important predictor of odor. Reporting stress or annoyance was strongly associated with increasing levels of H_2S; the OR for a 1 ppb change in H_2S was 1.18 (95%CI=1.08, 1.30). Hydrogen sulfide was also strongly associated with feeling nervous or anxious (OR=1.12; 95% CI=1.03, 1.22). Hydrogen sulfide did not appear to be associated with the other 3 mood state variables, and wind speed did not modify any of the relationships between H_2S and stress or mood.

We found that PM_{10} did not appear to be associated with stress or negative mood, with the exception of a marginal association with feeling confused or unable to concentrate (Table 3). Semivolatile PM_{10} was most strongly associated with feeling stressed or annoyed and nervous or anxious. Associated ORs for a 1 μg/m^3 increase in semivolatile PM_{10} were small (1.06 and 1.10, respectively), though ORs associated with a 10 μg/m^3 increase, for example, were 1.73 and 2.59, respectively. Semivolatile PM_{10} appeared to be only marginally associated with feeling gloomy, angry, or confused or unable to concentrate.

Table 3 also presents parameter estimates, standard errors, *t* values, ORs, and 95% CIs for reported malodor as a predictor of binary stress and negative mood. All parameter estimates were large relative to their standard errors. The ratio of the odds of reporting stress for a 1-unit increase in reported odor on a 0-to-8 scale was 1.81 (95% CI=1.63, 2.00). Consequently, a 4-unit change on the odor scale (from odor=0 to odor=4, for example) yielded an OR of 10.6. Odds ratios for feeling nervous, gloomy, angry, and unable to concentrate, associated with a 1-unit change in odor, were 1.60 (95% CI=1.41, 1.81); 1.43 (95% CI=1.25, 1.63); 1.52 (95% CI=1.37, 1.70) and 1.31 (95% CI=1.16, 1.50), respectively.

Coping, but not age, appeared to modify the relationship between reported odor and stress. The parameter estimate for participants who scored below the median on the John Henryism Active Coping scale was 0.45 (standard error [SE]=0.07), whereas the parameter estimate for participants who scored above the median was 0.73 (SE=0.08). Threshold odor sensitivity did not appear to modify the associations between reported malodor and stress or negative mood.

DISCUSSION

We used a longitudinal design to evaluate relationships between malodor from industrial hog operations, H_2S, PM_{10}, semivolatile PM_{10}, and the stress and negative mood reported by neighboring residents. We found that ratings of

TABLE 2—Number and Percentage of Records and Number of Participants in Each Category of the Odor, Stress, and Mood Variable Ratings: Community Health Effects of Industrial Hog Operations Study, Eastern North Carolina, 2003–2005

	Twice-Daily Odor Rating		Stressed or Annoyed		Nervous or Anxious		Gloomy, Blue, or Unhappy		Angry, Grouchy, or Bad-Tempered		Confused or Unable to Concentrate	
Rating	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants
0	1374 (51.5)	88	2162 (81.1)	98	2314 (86.8)	100	2337 (87.7)	98	2479 (93.0)	99	2529 (94.9)	100
1	472 (17.7)	82	290 (10.9)	60	217 (8.1)	40	198 (7.4)	44	109 (4.1)	40	96 (3.6)	24
2	273 (10.2)	72	95 (3.6)	39	80 (3.0)	24	42 (1.6)	20	22 (0.8)	11	20 (0.8)	9
3	196 (7.4)	68	50 (1.9)	20	34 (1.3)	12	45 (1.7)	13	10 (0.4)	7	10 (0.4)	4
4	123 (4.6)	47	14 (0.5)	10	10 (0.4)	3	12 (0.5)	6	6 (0.2)	5	7 (0.3)	2
5	73 (2.7)	39	22 (0.8)	13	8 (0.3)	6	13 (0.5)	6	17 (0.6)	9	3 (0.1)	3
6	108 (4.1)	40	19 (0.7)	10	1 (<0.1)	1	8 (0.3)	4	10 (0.4)	4	1 (<0.1)	1
7	22 (0.8)	12	6 (0.2)	4	1 (<0.1)	1	6 (0.2)	3	5 (0.2)	3	0 (0.0)	0
8	25 (0.9)	12	8 (0.3)	6	1 (<0.1)	1	5 (0.2)	3	8 (0.3)	3	0 (0.0)	0
Total	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101

feeling stressed or annoyed, nervous or anxious, gloomy or unhappy, angry or grouchy, and confused or unable to concentrate increased with ratings of malodor. Of the 5 outcome variables, odor was most strongly related to feeling stressed or annoyed. Active coping appeared to modify the relationship between odor and stress or annoyance, with those with higher John Henryism scores more affected by malodor. Hydrogen sulfide appeared to be associated with feeling stressed or annoyed and nervous or anxious but not with the other 3 mood variables. We found that PM_{10} was not associated with the outcome variables, with the exception of a marginal association with feeling confused or unable to concentrate. Semivolatile PM_{10}, however, appeared to be associated with feeling stressed or annoyed and nervous or anxious and only marginally associated with the remaining 3 mood variables.

Though we are not aware of other work that has sought to link airborne emissions to reported stress and negative mood, there is a consistent literature documenting the effect of malodor on annoyance, both in laboratories[1,37,51–53] and other settings.[3,29,30] Several authors have also considered coping style as a potential effect modifier.[1,3,29,30,37] In field studies of annoyance response to industrial odors, people with higher scores for problem-oriented coping, or action-oriented coping, tended to report more annoyance following odor exposure than did people with lower scores.[3,29,30,37] In a laboratory study, however, Asmus and Bell did not find coping style to be an effect modifier.[1]

We found a stronger relationship between odor and stress in participants with high scores on the John Henryism Active Coping scale. Our findings are consistent with odor studies by Steinheider and Winneke,[29] Winneke et al.,[37] Sucker et al.,[30] and Both et al.[3] The John Henryism Active Coping scale was developed by Sherman James in studies conducted among African Americans in eastern North Carolina[46] and, therefore, may be especially appropriate in the context of the present investigation. It measured "the degree to which [Black Americans] felt they could control their environment through hard work and determination."[46(p259)] James hypothesized a poorer health outcome (higher blood pressure) in men who scored high on the scale but lacked the resources to control their environments.[46] Consistent with our a priori hypothesis, it appears that study participants who perceived that they had more control over their environment found an unpredictable and uncontrollable malodor more stressful than those who perceived they had less control.

Strengths and Limitations

The longitudinal design was a particular strength of this research. There were approximately 28 repeated measures for each participant. In the analyses, each participant served as her or his own control. Perceptions of stress and adverse mood vary between people, and we were able to statistically model the between-person variation in such perceptions. Physical measures of pollution are an additional strength of this research; previous studies have relied entirely on self-reported measures of exposure and outcome. We did, however, measure only several constituents of a chemically complex odor plume that includes, potentially, hundreds of volatile organic compounds.[23]

A further design limitation was the contemporaneous assessment of both exposure and outcome for the analyses of odor as a predictor of stress and negative mood. Because both exposure and outcome were assessed by self-report, it is difficult to determine how the assessment of one affected the assessment of the other. Participants spent 10 minutes outdoors before returning indoors to complete the required data collection activities; they rated the intensity of any malodor present and then rated stress and mood. Rating the odor while stressed or annoyed for reasons unrelated to odor may have induced a higher rating than the participant would have rated in the absence of feeling stressed or annoyed. Though the results of the analyses of odor and stress or mood must be interpreted in light of this design limitation, odor as a marker of exposure is important because it captures information on numerous other pollutants with odorant properties that we were unable to explicitly measure in this study. Furthermore, it permits consideration of the mixture of chemicals emitted from industrial hog

TABLE 3—Logistic Mixed Model Results for Associations Between Hydrogen Sulfide, PM_{10}, Semivolatile PM_{10}, Odor, Stress, and Negative Mood: Community Health Effects of Industrial Hog Operations Study, Eastern North Carolina, 2003–2005

Main Exposure and Outcome Variable	b	SE	*t*	OR (95% CI)
Hydrogen sulfide (ppb)				
Stressed or annoyed	0.17	0.048	3.54	1.18 (1.08, 1.30)
Nervous or anxious	0.11	0.044	2.55	1.12 (1.03, 1.22)
Gloomy, blue, or unhappy	0.012	0.063	0.18	1.01 (0.89, 1.15)
Angry, grouchy, or bad-tempered	0.039	0.047	0.84	1.04 (0.95, 1.14)
Confused or unable to concentrate	–0.074	0.12	–0.63	0.93 (0.73, 1.17)
PM_{10} ($\mu g/m^3$)				
Stressed or annoyed	0.00065	0.0051	0.13	1.00 (0.99, 1.01)
Nervous or anxious	0.0029	0.0052	0.57	1.00 (0.99, 1.01)
Gloomy, blue, or unhappy	0.012	0.010	1.11	1.01 (0.99, 1.03)
Angry, grouchy, or bad-tempered	0.0035	0.0057	0.61	1.00 (0.99, 1.01)
Confused or unable to concentrate	0.010	0.0070	1.43	1.01 (1.00, 1.02)
Semivolatile PM_{10} ($\mu g/m^3$)				
Stressed or annoyed	0.055	0.025	2.15	1.06 (1.00, 1.11)
Nervous or anxious	0.095	0.033	2.91	1.10 (1.03, 1.17)
Gloomy, blue, or unhappy	0.058	0.043	1.35	1.06 (0.97, 1.16)
Angry, grouchy, or bad-tempered	0.027	0.026	1.05	1.03 (0.98, 1.08)
Confused or unable to concentrate	0.043	0.036	1.22	1.04 (0.97, 1.12)
Twice daily odor rating (0–8)				
Stressed or annoyed	0.59	0.051	11.50	1.81 (1.63, 2.00)
Nervous or anxious	0.47	0.064	7.37	1.60 (1.41, 1.81)
Gloomy, blue, or unhappy	0.36	0.067	5.35	1.43 (1.25, 1.63)
Angry, grouchy, or bad-tempered	0.42	0.055	7.70	1.52 (1.37, 1.70)
Confused or unable to concentrate	0.27	0.065	4.20	1.31 (1.16, 1.50)

Note. OR = odds radio; CI = confidence interval; PM_{10} = particulate matter less than 10 μm in aerodynamic diameter. Adjusted for time of day, morning versus evening.

operations as opposed to its individual constituent parts.

Conclusions

In a community-based, longitudinal study of neighbors of industrial hog operations, we observed associations among malodor, several airborne emissions, stress, and negative mood. Specifically, we observed increased reporting of stress and negative mood in response to increasing malodor. Additionally, increases in H_2S and semivolatile PM_{10}, both odorous in nature, were associated with reported stress and 1 or more mood variables. Our findings complement a large literature on malodor as an environmental stressor. Malodor and concomitant airborne emissions do appear to trigger stress and negative mood in nearby residents unwillingly exposed at home.

It is important to contextualize the effect of malodor on the lives of nearby residents. People who cannot afford air conditioning, clothes dryers, membership at a gym, and entertaining in restaurants depend on opening their windows for ventilation, drying their clothes outside, exercising in their yards, and entertaining family and friends in and around their homes. In ethnographic interviews, neighbors of industrial hog operations report that they refrain from gardening, walking, chores, and having cookouts with family and friends because of hog odor, and they report interruption of their sleep because of hog odor inside their homes.[54] This is significant, because physical activity, social support, and sleep are important for health. Industrial hog operations in North Carolina are located disproportionately in low income, African American communities[35] that have limited financial resources to prevent the influx of polluting industries as well as to manage the impacts of uncontrollable environmental malodors on physical and mental health. Recognizing that health is a state of well-being, and not merely the absence of disease,[40] public health and environmental professionals should consider the impacts of environmental malodor and its potential role in magnifying health disparities. ■

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Contributors

R. Avery Horton had primary responsibility for the study, completed the analyses, and wrote the first draft. S. Wing actively provided consultation throughout all phases of the research. S.W. Marshall provided statistical expertise in the design and analysis of data. K.A. Brownley consulted in the design phase and in the interpretation and contextualization of the results. All authors contributed to the writing of the article.

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Human Participant Protection

This study was approved annually by the institutional review board of the University of North Carolina at Chapel Hill. All study participants provided informed consent.

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Exhibit 9 to the
Declaration of Professor Steven B. Wing, Ph.D.

Air Pollution from Industrial Swine Operations and Blood Pressure of Neighboring Residents

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Background: Industrial swine operations emit odorant chemicals including ammonia, hydrogen sulfide (H_2S), and volatile organic compounds. Malodor and pollutant concentrations have been associated with self-reported stress and altered mood in prior studies.

Objectives: We conducted a repeated-measures study of air pollution, stress, and blood pressure in neighbors of swine operations.

Methods: For approximately 2 weeks, 101 nonsmoking adult volunteers living near industrial swine operations in 16 neighborhoods in eastern North Carolina sat outdoors for 10 min twice daily at preselected times. Afterward, they reported levels of hog odor on a 9-point scale and measured their blood pressure twice using an automated oscillometric device. During the same 2- to 3-week period, we measured ambient levels of H_2S and PM_{10} at a central location in each neighborhood. Associations between systolic and diastolic blood pressure (SBP and DBP, respectively) and pollutant measures were estimated using fixed-effects (conditional) linear regression with adjustment for time of day.

Results: PM_{10} showed little association with blood pressure. DBP [β (SE)] increased 0.23 (0.08) mmHg per unit of reported hog odor during the 10 min outdoors and 0.12 (0.08) mmHg per 1-ppb increase of H_2S concentration in the same hour. SBP increased 0.10 (0.12) mmHg per odor unit and 0.29 (0.12) mmHg per 1-ppb increase of H_2S in the same hour. Reported stress was strongly associated with BP; adjustment for stress reduced the odor–DBP association, but the H_2S–SBP association changed little.

Conclusions: Like noise and other repetitive environmental stressors, malodors may be associated with acute blood pressure increases that could contribute to development of chronic hypertension.

Key words: agriculture, air pollution, community-based participatory research, environmental justice, epidemiology, health disparities, odors, psychosocial stress. *Environ Health Perspect* 121:92–96 (2013). http://dx.doi.org/10.1289/ehp.1205109 [Online 28 October 2012]

The rapid global expansion of confined animal feeding operations (CAFOs) has created environmental health concerns at local, regional, and global scales, including infectious and respiratory diseases, reduced quality of life, impacts on the built environment, and environmental injustice (Pew Commission on Industrial Food Animal Production 2008). CAFO airborne emissions, including ammonia, hydrogen sulfide (H_2S), volatile organic compounds, and endotoxins, originate from confinement buildings, waste storage areas, and land application of animal waste (National Research Council 2003).

North Carolina experienced a rapid transformation of swine production during the 1980s and 1990s. The number of producers declined, the size of operations grew, the swine population increased from approximately 2.5 million to 10 million, and production shifted to the eastern coastal plain region of the state (Furuseth 1997). In North Carolina, swine CAFOs are concentrated in low-income communities of color (mostly African American), where older housing and lack of central air conditioning could increase human exposure to air pollutants (Wing et al. 2000). Studies conducted in Germany and the United States reported that neighbors describe odors from swine CAFOs as annoying and offensive (Schiffman 1998; Tajik et al. 2008; Thu 2002, 2003; Thu and Durrneberger 1998; Radon et al. 2007). In a previous study of communities neighboring North Carolina CAFOs (Schinasi et al. 2011), we found that self-reported hog odor and H_2S are associated with acute irritation of the eyes, nose, and throat, and also that particulate matter ≤ 10 μm in aerodynamic diameter (PM_{10}) is associated with eye irritation. In addition to physical symptoms and negative mood (Bullers 2005; Horton et al. 2009; Schiffman et al. 1995), CAFO neighbors have reported that because of frequent and unpredictable episodes of malodor, they were unable to engage in valued traditions of rural life, including gardening, family gatherings, cookouts, visiting neighbors, and drying laundry (Tajik et al. 2008; Thu 2002, 2003; Thu and Durrneberger 1998).

Several studies have found relationships between malodor from swine CAFOs and chronic (Schiffman et al. 1995) or acute (Horton et al. 2009) stress in neighbors. Other studies have reported that environmental stressors are associated with increased blood pressure (BP) (Attarchi et al. 2012; Belojevic and Evans 2012; Djindjic et al. 2012) and that odorant compounds perceived as pleasant attenuated exercise-related increases in BP (Nagai et al. 2000). African Americans and low-income people experience an excess prevalence of chronic hypertension (Carson et al. 2011; Keenan and Rosendorf 2011; Liao et al. 2011), as well as hypertension-related morbidity (Liao et al. 2011) and mortality (Fiscella and Holt 2008). Identification of environmental factors that contribute to BP elevations could inform efforts to prevent upward shifts of BP in populations.

In this study we evaluated whether measures of swine CAFO air pollution were associated with acute changes in BP among neighbors during follow-up of approximately 2 weeks. We did not compare BPs of CAFO neighbors and other people; rather, we compared each participant's BP during times of more and less exposure to swine CAFO air pollution. In this design each participant served as her or his own control. Characteristics that were essentially constant during the short follow-up (e.g., age, socioeconomic status,

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J. Creason, D. Taylor Davis, B. Denzler, J. Godwin, B. Graham, G.R. Grant, S. Hutton, A. Lowman, N. Muhammad, J.W. Scott, J. Thompson, J. Watkins, and S. Wolf played key roles in field work and study support. S. Wolf, J. Creason, K. Foarde, J. Raymer, and S. Schiffman helped to design the study. C. Gray provided research assistance. The Concerned Citizens of Tillery, the Alliance for a Responsible Swine Industry, and other community-based organizations, which must remain unnamed to protect confidentiality, contributed to the design and conduct of the research. We are indebted to the study participants for their hard work and commitment to collection of data.

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S.W. provided pro bono testimony in legal proceedings related to landfills and provided pro bono advice on radiation and health for law firms, one of which made a gift to the University of North Carolina. He conducted research, funded by the Water and Environment Research Foundation, on symptoms reported by neighbors of areas where sewage sludge is applied to land. The other authors declare they have no actual or potential competing financial interests.

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medical history, body mass, occupation, personality) could not cause bias in estimates of the exposure–outcome relationship. Chronic effects of exposure, however, could not be evaluated.

Methods

Setting and data collection. The study was conducted in partnership with the Concerned Citizens of Tillery (CCT), a community-based organization in Halifax County that promotes the health, environmental, and political interests of predominantly African-American communities in eastern North Carolina (Wing et al. 1996). CCT has partnered with universities to provide medical care through the Tillery People's Clinic and to conduct research on health and environmental justice (Tajik and Minkler 2006). For this study, the CCT staff organized community meetings in areas with a high density of swine CAFOs and provided information about our ongoing study to attendees, who were invited to contact CCT or University of North Carolina–Chapel Hill researchers if they were interested in participating in the study (Wing et al. 2008a). We sequentially enrolled between 4 and 10 volunteers in each of 16 rural communities from 2003 to 2005, and participants began data collection within 24–36 hr. Enrollment did not take place between mid-December and mid-February because of holidays and cold weather. Numbers of nearby swine CAFOs, participants, and other community-specific characteristics have been reported previously (Wing et al. 2008b).

To be eligible, participants had to be ≥ 18 years of age and nonsmokers, and live within 1.5 miles of at least one swine CAFO (Wing et al. 2008a), defined as a facility housing > 250 animals and using a liquid waste management system (Wing et al. 2000). At an initial training session, participants chose morning and evening times when they would sit outside each day for approximately 2 weeks (in three neighborhoods participants chose to continue up to 1 more week). They provided information about regular use of medications, and each participant's odor sensitivity was tested using a standard set of butanol dilutions to evaluate the lowest concentration that could be distinguished from zero (e.g., Croy et al. 2009). Participants completed the John Henryism Active Coping (JHAC) scale, which measures the predisposition to respond behaviorally to psychosocial environmental stressors (James et al. 1987); higher values indicate a greater predisposition to cope actively. Participants were classified by reported use (yes/no) of antihypertensive medications (e.g., drugs classified as beta blockers, calcium channel blockers, angiotensin-converting-enzyme inhibitors, diuretics). They learned how to use a structured diary to record levels of swine odor, stress, and symptoms, and they practiced measuring their BP with an automated oscillometric device. Time spent outdoors and times of diary completion were tracked using a digital clock provided and set by researchers. Informed consent was obtained at the training session using a procedure approved by the University of North Carolina Institutional Review Board, which reviewed the study annually. We obtained a Certificate of Confidentiality from the National Institutes of Health (Wing et al. 2008a) because of prior attempts by the pork industry to obtain confidential records (Wing 2002).

Each morning and evening, participants sat outside for 10 min and completed the first of four pages of a data-collection diary. They then returned indoors to complete the remaining pages and measure their BP (Wing et al. 2008a). They rated the strength of swine odor during the 10-min period outdoors on a nine-level Likert-type scale [0 (none) to 8 (very strong)], and evaluated perceived stress ("How do you feel now … stressed or annoyed?) on a nine-level scale [0 (none) to 8 (extremely)]. Participants measured their BP twice in a seated position. They were instructed to wait 1 min between readings, raising their right arm above their head for the first 30 sec and then resting for the remaining time before taking their BP again. They printed the results and taped the printout with the systolic (SBP) and diastolic (DBP) values and current time into the diary. We treated the average of the two readings as dependent variables.

While participants collected data, we monitored air pollution at a central location in each neighborhood. The mean and median distance from air monitors to participant homes was 0.2 miles and 0.1 miles, respectively (Wing et al. 2008a). Swine CAFOs release many odorant chemicals including ammonia, H_2S, and hundreds of volatile organic compounds (Schiffman et al. 2001). Odorant chemicals may occur as gases or particles. We quantified H_2S, which is produced by the anaerobic decomposition of fecal waste, as a marker of this complex mixture that is related to hog odor intensity (Wing et al. 2008b; Schiffman et al. 2005). H_2S is a specific marker of swine CAFO pollution in the study areas because other H_2S-emitting industries such as waste water treatment plants, petrochemical plants, and paper mills, were not present. Average ambient H_2S concentrations measured every 15 min with an MDA Scientific Single Point Monitor (Zellweger Analytics Inc., Lincolnshire, IL) were used to calculate hourly averages; 15-min values below the detection limit of 2 ppb were treated as zero. We considered average concentrations during the 1 hr before BP measurements as predictors of SBP and DBP.

We measured hourly levels of PM_{10} using a Series 1400a tapered element oscillating microbalance Ambient Particulate Monitor (Rupprecht and Patashnick Co. Inc., East Greenbush, NY). A Series 8500 FDMS Filter Dynamics Measurement System (Rupprecht and Patashnick Co. Inc.) was used to quantify semivolatile PM_{10}. Semivolatile particles consist of compounds that are present in both vapor and condensed phases. Airborne PM is ubiquitous; although CAFOs are one source, particles are not a specific marker of CAFO pollutants. We reported previously that semivolatile PM_{10} showed little association with hog odor in the study neighborhoods and that PM_{10} was related to hog odor only when wind speeds were high (Wing et al. 2008b).

Statistical analysis. In this repeated-measures design, each participant served as her or his own control. The sample size is a function of the number of participants and the number of observations (records) per person. We used linear fixed-effects regression to model repeated measures for individuals (Allison 2005). This approach estimates the average within-person associations between exposure measures and BP by conditioning on person, and eliminates bias from any measured or unmeasured confounding factors that do not change during follow-up. Relationships between SBP and DBP and air pollution appeared linear across categories of exposure (data not shown), so they were modeled as continuous variables. BP varies diurnally, as do hog odor and H_2S (Wing et al. 2008b); therefore, time of day (AM vs. PM) was included as a covariate in all models. In separate analyses, we also adjusted for self-reported stress, a potential mediator of associations between pollutants and BP. Sex and odor detection threshold (dichotomized at the median) were considered potential modifiers related to odor perception, whereas JHAC score (dichotomized at the median) and use of antihypertensive medication (yes/no) were considered potential modifiers of BP reactivity to environmental stressors. We also considered modification by age (dichotomized at the median) because it could influence either odor perception or BP reactivity.

Observations (records) with missing values for a variable were dropped from models including that variable. Model coefficients represent the average within-person change in BP for each unit increase in pollution. In nonrandomized studies, confidence limits and *p*-values do not quantify the confidence or probability that a point estimate would occur within a specified interval due to chance; therefore, we report standard errors of the regression coefficients as a measure of precision and *t*-values as indicators of the improvement in the fit of the model associated with the exposure variable. Degrees of freedom for *t*-tests, *n*-1, are large and can be considered equivalent for comparing *t* values.

Results

Descriptive characteristics of the 101 participants are given in Table 1. Half of the participants were > 53 years of age, and two-thirds were women. Among the 97 participants whose odor detection threshold was determined, 55 had a butanol odor detection threshold of ≤ 40 ppm. Forty-two participants reported taking one or more BP medications. Among the 96 participants who completed the JHAC, 46 had a score > 52. Most participants (85) identified themselves as black.

Table 2 presents distributions of reported hog odor intensity during the 10 min outdoors, average pollutant concentrations in the hour before BP measurement, SBP, and DBP. Odor ratings were missing in 6% of the records, and no odor was reported in 48% of the records. Very strong odor (a rating of 6, 7, or 8) was reported 6% of the time. Hourly H_2S measurements were missing in approximately 9% of the records, and most (88%) were below the limit of detection (2 ppb). PM measures were missing in 32.2% of the records, primarily because of equipment malfunction during periods of high temperature and humidity (Wing et al. 2008b). For 12.4% of records, semivolatile particle concentrations were < 0; this occurs when concentrations are low because microbalance estimates are derived by subtraction of sequential mass values that are measured with error (Wing et al. 2008b). BP was missing in 1.4% of the records. SBP readings were < 120 mmHg in approximately 30% of the records and > 140 mmHg in approximately 25% of the records. DBP was < 80 mmHg in 61% of the records and ≥ 90 mmHg in 11% of the records. No participants were missing data for all their records.

Associations between air pollutants and BP adjusted for time of day (AM or PM) are presented in Table 3. Each unit increase in reported hog odor on the 0–8 intensity scale was associated with average estimated increases [β (SE)] of 0.10 (0.12) and 0.23 (0.08) mmHg for SBP and DBP, respectively. A 1-ppb increase in H_2S was associated with increases of 0.29 (0.12) mmHg for SBP and 0.12 (0.08) mmHg for DBP. PM_{10} was not associated with BP. Semivolatile PM_{10} was not associated with SBP but had a small negative association with DBP [–0.06 (0.03)].

Table 4 provides beta coefficients for hog odor and H_2S according to potential modifying variables. Coefficients for PM_{10} and semivolatile PM_{10} are not shown because their main effect estimates were small, they are not specific markers of swine CAFO air pollution, and data are missing for almost one-third of the records. Hog odor coefficients for SBP were all positive, but none had *t*-values > 1.17. Coefficients for DBP were positive and all had *t*-values near or above 2 except for participants ≤ 53.7 years of age, for whom the β (SE) is 0.08 (0.12). Coefficients for both SBP and DBP were larger for older participants than younger participants [0.14 (0.15) and 0.33 (0.10) vs. 0.04 (0.18) and 0.08 (0.12), respectively] and for men than women [0.20 (0.23) and 0.36 (0.15) vs. 0.07 (0.13) and 0.19 (0.09), respectively]. Associations between hog odor and SBP were larger for participants with JHAC scores ≤ 52 compared with those for persons with JHAC scores > 52 [0.18 (0.17) compared with 0.01 (0.16)] and for participants who reported no use of antihypertensive drugs compared with those with regular use [0.19 (0.16) compared with 0.01 (0.17)]. For H_2S, coefficients for both SBP and DBP were larger for men than women [0.56 (0.30) and 0.48 (0.19) compared with 0.24 (0.13) and 0.05 (0.08), respectively]; participants with butanol odor sensitivity thresholds > 40 ppm than for those with thresholds ≤ 40 ppm [0.33 (0.14) and 0.13 (0.09) compared with 0.17 (0.22) and 0.07 (0.14), respectively]; and participants with JHAC scores of ≤ 52 than those with scores > 52 [0.36 (0.14) and 0.17 (0.09) compared with 0.02 (0.24) and –0.07 (0.15), respectively]. The SBP coefficient was larger for participants who did not report taking BP medications compared with those who did [0.38 (0.14) compared with 0.07 (0.22)].

SBP and DBP were strongly associated with reported stress, increasing on average 0.82 (0.21; t = 3.98) and 0.57 (0.13 mmHg; t = 4.28), respectively, for every unit increase on the 0–8 scale. We included stress in models reported above (in addition to time of day) to evaluate whether associations of BP with hog odor and H_2S change after adjustment for this potential mediator. With adjustment for reported stress, coefficients for the association between hog odor and DBP declined from 0.23 (0.08) to 0.15 (0.08), whereas the coefficient for SBP decreased from 0.10 (0.12) to –0.04 (0.12). With adjustment for reported stress, there was little change in the coefficient for the association between H_2S and DBP [0.15 (0.08) vs. 0.12 (0.08) before adjustment] or SBP [0.26 (0.12) vs. 0.29 (0.12) before adjustment].

Discussion

In this community-based participatory repeated-measures study we found that, on average, BP of participants living near swine CAFOs increased in association with increases in markers of transient plumes of odorant air pollution. Because each participant served as her or his own control, factors that did not change during the 2-week study—including body mass, race, socioeconomic position, medical and dietary history, and prior BP—could not

Table 1. Characteristics of participants [*n* (%) of nonmissing observations], Community Health Effects of Industrial Hog Operations study.

Variable	Participants (*N* = 101)	Records (*N* = 2,949)
Age (years)		
≤ 53.7	51 (50.5)	1,410 (47.9)
> 53.7	50 (49.5)	1,539 (52.2)
Gender		
Women	66 (65.3)	1,945 (66.0)
Men	35 (34.7)	1,004 (34.0)
Odor threshold		
Missing[a]	4 (4.0)	91 (3.1)
Butanol ≤ 40ppm	55 (56.7)	1,559 (54.5)
Butanol > 40ppm	42 (43.3)	1,299 (45.5)
BP medication used		
No	59 (58.4)	1,680 (57.0)
Yes	42 (41.6)	1,269 (43.0)
JHAC score[b]		
Missing[a]	5 (5.0)	117 (4.0)
≤ 52	50 (52.1)	1,480 (52.3)
> 52	46 (47.9)	1,352 (47.7)

[a]Percent of all observations. [b]Higher JHAC score indicates higher active coping with psychosocial stressors.

Table 2. Distributions of odor, H_2S, and BP from the total of nonmissing records (*N* = 2,949), Community Health Effects of Industrial Hog Operations study.

Variable (scale)	*n* (%)
Odor (0–8)	
Missing[a]	177 (6.0)
None	1,419 (48.1)
1–2	779 (26.4)
3–5	407 (13.8)
6–8	167 (5.7)
Stress (0–8)	
Missing[a]	58 (2.0)
None	2,331 (80.6)
1–2	436 (15.1)
3–5	91 (3.2)
6–8	33 (1.2)
H_2S (ppb)	
Missing[a]	255 (8.6)
0	2,412 89.5
0–2	170 (6.3)
2–4.99	77 (2.9)
5–47.5	35 (1.3)
PM_{10} (μg/m^3)	
Missing[a]	948 (32.1)
< 10	415 (20.7)
10–19.9	783 (39.1)
20–29.9	528 (26.4)
30–502.0	275 (13.7)
Semivolatile PM_{10} (μg/m^3)	
Missing[a]	948 (32.2)
< 0	366 (18.3)
0–2.99	638 (31.9)
3–7.99	767 (38.3)
> 8	230 (11.5)
SBP (mmHg)	
Missing[a]	41 (1.4)
< 120	897 (30.8)
120–139	1,257 (43.2)
140–159	510 (17.5)
> 160	244 (8.4)
DBP (mmHg)	
Missing[a]	41 (1.4)
< 80	1,804 (62.0)
80–89	781 (26.9)
90–99	221 (7.6)
> 100	102 (3.5)

[a]Percent of all records.

confound these associations. Estimated DBP was almost 2 mmHg higher during periods of very strong odor (a rating of 8) compared to none, and estimated SBP was almost 3 mmHg higher when H_2S concentrations were 10 ppb compared with times when H_2S was zero (below the limit of detection). This magnitude of effect could have public health importance because of the frequency and duration of odor episodes near CAFOs. The 101 people who participated in this study for approximately 2 weeks reported 1,655 episodes of outdoor hog odor, 38% of which lasted > 1 hr, and 17% of which had a mean odor ≥ 5 (on the scale of 0–8); participants also reported 500 episodes of indoor odor (Wing et al. 2008b). If the associations were causal and if malodors from other sources such as sewage, landfills, and chemical refineries produce similar effects, then control of environmental malodor might help prevent repeated acute elevations of BP that could contribute to development of chronic hypertension.

With approximately 29 measures per person, the sample size for this study was primarily suited to examining within-person covariation in exposures and outcomes. Although estimates within subgroups defined by non–time-varying factors are imprecise, some interactions are of interest. Associations between H_2S and SPB were similar for both older and younger participants, whereas the odor–DBP association was observed primarily among older participants. Beta coefficients for both odor and H_2S were larger for men than women. The magnitude of the association between BP and hog odor was not related to the butanol odor sensitivity threshold. Because the effectiveness of peoples' active coping is reduced by lack of resources, persons with high JHAC scores and low socioeconomic position are expected to be more physiologically reactive to psychosocial stressors than people with high JHAC scores and high socioeconomic position, or people with low JHAC scores (James et al. 1987). Contrary to our expectation, even though all participants in this study lived in low-income areas, associations between hog air pollution markers and BP were not stronger among participants with high JHAC scores. Associations for SBP were generally weaker among participants who were taking BP medications, which may reduce responses to environmental stimuli.

Table 3. Linear fixed effects beta coefficients (SEs) and *t*-values for associations of one-unit increases in pollutants with SBP and DBP, adjusted for time-of-day (AM or PM), Community Health Effects of Industrial Hog Operations study.

	SBP		DBP	
Pollutant	β (SE)	*t*-Value	β (SE)	*t*-Value
Odor (0–8)	0.10 (0.12)	0.86	0.23 (0.08)	3.02
H_2S (ppb)	0.29 (0.12)	2.45	0.12 (0.08)	1.52
PM_{10} (μg/m^3)	–0.01 (0.01)	–0.78	–0.00 (0.01)	–0.41
Semivolatile PM_{10} (μg/m^3)	–0.02 (0.05)	–0.45	–0.06 (0.03)	–1.66

Table 4. Linear fixed effects beta coefficients (SEs) and *t*-values for potential modifiers of associations of BP with one-unit increases in hog odor and H_2S, adjusted for time-of-day (AM or PM), Community Health Effects of Industrial Hog Operations study.

	SBP		DBP	
Modifier	β (SE)	*t*-Value	β (SE)	*t*-Value
Hog odor (0–8)				
Age ≤ 53.7 years	0.04 (0.18)	0.23	0.08 (0.12)	0.68
Age > 53.7 years	0.14 (0.15)	0.93	0.33 (0.10)	3.34
Women	0.07 (0.13)	0.50	0.19 (0.09)	2.11
Men	0.20 (0.23)	0.85	0.36 (0.15)	2.37
Butanol threshold ≤ 40 ppm	0.10 (0.15)	0.67	0.21 (0.10)	2.17
Butanol threshold > 40 ppm	0.10 (0.19)	0.54	0.24 (0.12)	2.03
JHAC score ≤ 52	0.18 (0.17)	1.07	0.22 (0.11)	2.05
JHAC score > 52	0.01 (0.16)	0.06	0.20 (0.11)	1.92
No BP meds	0.19 (0.16)	1.17	0.25 (0.11)	2.31
Any BP meds	0.01 (0.17)	0.04	0.21 (0.11)	1.96
H_2S (ppb)				
Age ≤ 53.7 years	0.30 (0.15)	1.97	0.13 (0.10)	1.32
Age > 53.7 years	0.28 (0.19)	1.45	0.10 (0.12)	0.78
Women	0.24 (0.13)	1.85	0.05 (0.08)	0.58
Men	0.56 (0.30)	1.90	0.48 (0.19)	2.51
Butanol threshold ≤ 40 ppm	0.17 (0.22)	0.78	0.07 (0.14)	0.48
Butanol threshold > 40 ppm	0.33 (0.14)	2.40	0.13 (0.09)	1.49
JHAC score ≤ 52	0.36 (0.14)	2.67	0.17 (0.09)	1.90
JHAC score > 52	0.02 (0.24)	0.08	–0.07 (0.15)	–0.45
No BP medication	0.38 (0.14)	2.70	0.10 (0.09)	1.12
Any BP medication	0.07 (0.22)	0.34	0.15 (0.14)	1.07

Although the repeated-measures design and fixed-effects analysis precludes confounding from time-independent factors that differ between people, time-related factors associated with both air pollution and BP could have either attenuated or exaggerated associations. Time of day (AM vs. PM) was included in all models; therefore, potential time-related factors would need to be associated with pollution and BP within times of day in order to act as confounders. Time-related confounding could occur if a cause of acute BP change that is not a consequence of CAFO air pollution covaried with the CAFO air pollutants in participants' neighborhoods.

Measurement errors could also impact estimates of association between odorant pollutants and BP. In a clinical or experimental setting, BP is typically measured by a trained technician in a standardized manner. In contrast, in the present study, each participant measured her or his own BP twice each day at home, which could reduce the precision of the effect estimates. Use of a portable printer with a time stamp to record BP values in the diaries prevented transcription errors that could have introduced systematic errors related to odor intensity. The temporal sequence of sitting outside prior to BP measurement was reversed in < 2% of records (Schinasi et al. 2009).

Although participants recognized hog odor and could rate it on the 0–8 scale from "none" to "very strong," we did not evaluate the reproducibility of their ratings, which could be affected by physical and social context. For example, participants might rate an odor as more intense on a day that they expected company if they were ashamed of their expected guests' reactions to the presence of fecal odor at their home. More precise measures of odor can be made in units of dilution to threshold using an olfactometer (Lambert et al. 2000); however, it was not feasible to use such a device in this participatory study. We evaluated participants' odor sensitivity threshold using a butanol standard and expected that associations between hog odor and BP might be attenuated among participants with poorer odor sensitivity; however, associations with hog odor differed little by odor sensitivity. In an experiment including 44 volunteers, van Thriel et al. (2008) reported that butanol odor threshold was not related to ratings of environmental odorants.

H_2S was the chemical marker of odorant swine CAFO air pollution that we could quantify over short time period; these measures cannot be affected by response bias. Because there are no other major industrial sources of H_2S in the study communities, it is a specific marker of swine CAFO emissions; however, this marker is not sensitive, in part, because of the detection threshold of the instrument (~ 2 ppb/15 min). Hog odor, which has a distinctive character due to a complex mixture of volatile organic compounds (Schiffman et al. 2001; Karageorgos et al. 2010), was often reported when H_2S levels were below the detection limit. Another source of measurement error comes from the placement of the H_2S monitor at a central location in rural neighborhoods, which was as far as approximately 1 mile from some participants' residences (median, 0.1 mile). Narrow plumes of odorant compounds from swine CAFOs could be present at participants' homes but not at the monitor, or vice versa. We expect this type of exposure misclassification would attenuate any real associations between H_2S and BP.

Relationships between odorant air pollutants and BP could be produced by psychophysiological or pharmacological mechanisms (Shusterman 1992). Our findings that odor and H_2S, but not PM, were associated with BP increases are consistent with a psychophysiological mechanism. The lack of an association with PM could also be related to the lower levels or different composition of PM in rural communities compared with urban areas typically studied. Furthermore, many observations were missing for PM. We evaluated BP in this study because environmental exposure to swine odor in this population has been associated with self-reported stress (Horton et al. 2009), and acute stress is associated with transient BP elevation (Sparrenberger et al. 2009). Odorant pollution could also produce other changes in a person's environment that cause acute changes in BP, for example, irritability of a household member.

The pharmacological actions of swine CAFO air emissions on BP are unknown and difficult to predict because emissions include many chemical compounds and fine particles (Schiffman et al. 2001). Although we measured H_2S as an indicator of the odorant component of this mixture, growing evidence suggests that H_2S, an endogenous gasotransmitter, acts as a vasodilator (Wagner 2009). To the extent that exogenous H_2S plays a similar role, its presence in odorant plumes could therefore attenuate associations between swine odor and BP.

The setting for our study, the coastal plain of eastern North Carolina, has one of the highest densities of swine production in the world (Pew Commission on Industrial Food Animal Production 2008). Historically, it is part of both the Black Belt (home to a majority of rural African Americans) and the stroke belt (an area of high mortality from cerebrovascular and cardiovascular diseases) (Casper et al. 1995). Swine CAFOs in the state are highly disproportionately located in low-income communities of color (Wing et al. 2000). If swine CAFO air pollution contributes to high BP in this region, the associated cardiovascular morbidity and mortality would be among the consequences of environmental injustice.

Malodors are produced by other types of CAFOs, waste disposal sites, refineries, chemical plants, waste water treatment plants, and land application of sewage sludge. These facilities and activities expose communities that lack political power to environmental malodors while benefiting consumers and producers in nonimpacted areas. Therefore, the generalizability of findings reported here is relevant to public health protection. Communities with low levels of political influence are less able to prevent siting of such facilities than are communities with political power, and they are less able to demand the best technologies for reducing resulting pollutants. Repeated acute physical environmental stressors, such as malodor and noise, may be aspects of the built environment that contribute to racial and economic disparities in high BP and its sequelae.

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Exhibit 10 to the
Declaration of Professor Steven B. Wing, Ph.D.

Air Pollution, Lung Function, and Physical Symptoms in Communities Near Concentrated Swine Feeding Operations

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Background: Concentrated animal feeding operations emit air pollutants that may affect health. We examined associations of reported hog odor and of monitored air pollutants with physical symptoms and lung function in people living within 1.5 miles of hog operations.

Methods: Between September 2003 and September 2005, we measured hydrogen sulfide (H_2S), endotoxin, and particulate matter (PM_{10}, $PM_{2.5}$, and $PM_{2.5–10}$) for approximately 2-week periods in each of 16 eastern North Carolina communities. During the same time periods, 101 adults sat outside their homes twice a day for 10 minutes, reported hog odor and physical symptoms, and measured their lung function. Conditional fixed-effects logistic and linear regression models were used to derive estimates of associations.

Results: The log odds ($\pm$1 standard error) of acute eye irritation following 10 minutes outdoors increased by 0.53 ($\pm$0.06) for every unit increase in odor, by 0.15 ($\pm$0.06) per 1 ppb of H_2S, and by 0.36 ($\pm$0.11) per 10 $\mu g/m^3$ of PM_{10}. Odor and H_2S were also associated with irritation and respiratory symptoms in the previous 12 hours. The log odds of difficulty breathing increased by 0.50 ($\pm$0.15) per unit of odor. A 10 $\mu g/m^3$ increase in mean 12-hour $PM_{2.5}$ was associated with increased log odds of wheezing (0.84 $\pm$ 0.29) and declines in forced expiratory volume in 1 second (-0.04 ± 0.02 L). A 10 EU/mg increase in endotoxin was associated with increased log odds of sore throat (0.10 $\pm$ 0.05), chest tightness (0.09 $\pm$ 0.04), and nausea (0.10 $\pm$ 0.05).

Conclusions: Pollutants measured near hog operations are related to acute physical symptoms in a longitudinal study using analyses that preclude confounding by time-invariant characteristics of individuals.

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Concentrated animal feeding operations contribute to local, regional, and global air pollution.[1] Pollutants of local importance include odor,[2,3] hydrogen sulfide (H_2S),[4] endotoxin,[5] particulate matter (PM),[6,7] and ammonia (NH_3).[8,9]

Several cross-sectional studies have examined the health of people living near concentrated hog operations on the basis of residential proximity to classify exposure. In a population-based survey, neighbors of hog operations reported more episodes of headache, runny nose, sore throat, coughing, diarrhea, and burning eyes compared with demographically similar persons who did not live near a hog operation.[10] Among children, indicators of asthma have been related to measures of residential[11] and school[12,13] exposures to pollution from hog operations. In an area of Germany with a high density of concentrated animal feeding operations, reported odor annoyance was associated with prevalence of wheeze without a cold, and physician-diagnosed asthma and allergic rhinitis. Additionally, the number of operations within 500 meters of participants' homes was associated with increased odds of wheezing without a cold, and with diminished lung function.[14] These symptoms overlap with conditions reported in studies of occupational exposures of animal-confinement-house workers, including decreased lung function,[15–17] chronic cough,[17] excess phlegm production, chest tightness,[18] scratchy throat, eyes and mucous membrane irritation, shortness of breath,[16] and wheezing.[18]

Community Health Effects of Industrial Hog Operations was a longitudinal, community-driven, participatory study of air pollution, health, and quality of life among persons living near hog operations. We have previously described associations between air pollution and hog odor,[19] air pollution and measures of stress and negative mood,[20] and factors associated with data quality and completeness.[21] Here we report relationships between measures of air pollution, symptoms, and lung function, focusing on physical symptoms that have been of interest in cross-sectional studies.[22]

METHODS

Between September 2003 and September 2005, residents of 16 eastern North Carolina communities collected health data for approximately 2 weeks while pollutant concentrations were monitored continuously. Communities participated sequentially using the same set of air-monitoring devices.

Nonsmoking volunteers aged at least 18 years residing within 1.5 miles of at least one hog operation were recruited through community-based organizations. The lead community organization for this study was the Concerned Citizens of Tillery.[23] Participants attended a 3-hour training session at which they gave informed consent and practiced completing all data-collection activities. The study design has been described in detail elsewhere.[23]

The Institutional Review Board of the University of North Carolina at Chapel Hill reviewed and approved study activities annually.

Exposure Variables

Odor

Participants spent 10 minutes outdoors at preselected morning and evening times approximately 12 hours apart. While outside, they rated, on a scale of 0 (none) to 8 (very strong), the strength of the hog odor they recalled having smelled during each of the 12 preceding hours. Participants then returned indoors and rated hog odor present during the 10 minutes outside on the same 9-point scale.

We analyzed 2 hog odor variables. Twelve-hour mean odor is the average of the hourly odor levels reported for each of the 12 hours before the morning or evening data collection time. Twice-daily odor is the odor during the 10 minutes outdoors.

Air Monitoring

Continuous air pollution monitors, mounted on a trailer that was centrally located in each community, recorded concentrations of hydrogen sulfide (H_2S), semi-volatile particulate matter less than 10 micrometers in diameter (semivolatile PM_{10}), particulate matter less than 10 micrometers in diameter that excluded the volatile fraction (PM_{10}), coarse PM ($PM_{2.5-10}$), fine PM ($PM_{2.5}$), and endotoxin. An MDA Scientific Single Point Monitor (Honeywell Analytics Inc North America, Lincolnshire, IL) recorded H_2S concentrations every 15 minutes in parts per billion (ppb). Hourly concentrations of PM_{10} and semivolatile PM_{10} were measured in micrograms per cubic meter ($\mu g/m^3$), using a Tapered Element Oscillating Microbalance Series 1400a Ambient Particulate Monitor with a Series 8500 Filter Dynamics Measurement System (Thermo Fisher Scientific, Waltham, MA). In the first 12 of 16 communities, a Dichotomous Partisol-Plus 2025-D Sequential Air Sampler (Thermo Fisher Scientific, Waltham, MA) was used to collect 12-hour samples of $PM_{2.5-10}$ and $PM_{2.5}$ ($\mu g/m^3$) on filters that were assayed for endotoxin in endotoxin units per milligram (EU/mg). Endotoxin levels from $PM_{2.5-10}$ filters were quantified by kinetic chromogenic Limulus amebocyte lysate assay[24,25]; $PM_{2.5-10}$ filters contained approximately 60% of the endotoxin in the PM_{10}.

We calculated the mean concentrations of H_2S, PM_{10}, and semivolatile PM_{10} in the 1- and 12-hour periods that preceded the time at which participants sat outdoors for 10 minutes. Concentrations of $PM_{2.5}$, $PM_{2.5-10}$, and endotoxin were measured on 12-hour filters that typically did not correspond to exposure periods of interest. Thus, we estimated these exposures with a time-weighted average of the concentrations from filters exposed during the 12 hours prior to sitting outdoors. All exposure variables were coded continuously.

Outcome Variables

Given the short follow-up and focus on transient exposures, we analyzed symptoms that could appear and resolve during follow-up.

Physical Symptoms

After sitting outside their homes for 10 minutes and then returning inside, participants noted whether they experienced cough or irritation of the skin, eyes, nose, or throat while outside (Table 1). Symptoms of acute irritation, reported as present or absent, were analyzed in relation to odor levels reported for the same 10 minutes and in relation to averages of PM and H_2S in the hour prior to the time participants returned indoors. After returning indoors, participants rated the extent to which they experienced any of 19 acute physical symptoms in the preceding 12 hours on a scale of 0 (not at all) to 8 (extreme).

We considered the following 12-hour symptoms: respiratory (runny nose, mucus or phlegm, sore throat, cough, wheezing, difficulty breathing, chest tightness), irritation (burning eyes, itching eyes, nasal), gastrointestinal (nausea, diarrhea, poor appetite), neurologic (headache, dizziness), and other (aching joints, difficulty hearing, fever, and backache). Reports of most physical symptoms were uncommon, so we dichotomized them as absent versus present based on the distribution of responses for each symptom such that at least 85% of responses were coded as 0 and no more than 15% were coded as 1. Runny nose, mucus or phlegm, headache, cough, burning eyes, aching joints, nasal irritation, and itching eyes were dichotomized such that a response of 0 or 1 on the original scale was coded as 0 and a response of 2–8 was coded as 1. For the remaining symptoms, a response of 0 on the original scale was coded as 0 and 1–8 was coded as 1.

Lung Function

Participants used an AirWatch personal respiratory monitor (iMetrikus, Inc., Sunnyvale, CA) to measure forced

TABLE 1. Characteristics of Communities (n = 16) and Study Participants (n = 101)

Characteristic	No.
Concentrated swine feeding operations within 2 miles of community	
Median	9
Range	1–16
Permitted no. hogs (in thousands) within 2 miles of community	
Median	42
Range	4–77
Diary entries per participant	
Median	28
Range[a]	7–46
Race and sex	
Black women	57
Black men	28
Nonblack women	9
Nonblack men	7
Exposed to passive smoking[b]	5
Chronic respiratory disease[c]	
Emphysema[d]	0
Asthma[e]	5
Chronic bronchitis[e]	3
Asthma and chronic bronchitis	4
Hay fever allergy[f]	34
Dust, animal, or food allergy[d]	30
Grew up around livestock[g]	76

[a]Some participated for more than 2 weeks.
[b]Eligible participants were nonsmokers.
[c]Based on participant report of diagnosis by a physician at any point in his or her life.
[d]Number missing = 9.
[e]Number missing = 10.
[f]Number missing = 8.
[g]Number missing = 3.

expiratory volume in the first second (FEV_1) and peak expiratory flow rate (PEF) during each data collection session. The AirWatch internally recorded each of 3 attempts and flagged any that were made with problematic technique. The highest error-free FEV_1 and PEF measurements from each session (sometimes there were none) were included in the analysis as continuous outcome variables.

Statistical Analyses

In this longitudinal study of transient exposures and outcomes, each participant served as her or his own control. The analytic goal was to make valid within-participant comparisons to determine whether increases in air pollutant concentrations or odor ratings were associated with physical symptoms and lung function. Estimates of associations were constructed using conditional fixed-effects linear and logistic regression models. In these models, the within-person correlation due to repeated measures is accounted for by treating each person as a stratum within the model.[26] This approach has good control of measured and unmeasured time-invariant individual level confounders. These models account for the longitudinal nature of the data by modeling differences between individuals' time-specific characteristics and their mean value over the entire period of follow-up.

Time of day was integral to the study design because community members collected data at morning and evening times that were approximately 12 hours apart. Physical symptoms, lung function, and hog odors exhibit diurnal variation,[19] and thus we made an a priori decision to adjust for potential confounding due to time of day by including a term for morning versus evening in all models. There was little variance in community effects; therefore we did not include the community level in our models.

Because of the large number of exposure and outcome variables, we did not restrict analyses to participant records with complete data for all variables. Each analysis excludes only those observations that were missing data for the exposure and outcome being analyzed.

RESULTS

There was a median of 9 hog operations within 2 miles of participating communities, and the median number of hogs within that radius was approximately 42,000 (Table 1). Study participants ranged in age from 19 to 90; their mean age was 53. Over half of participants were women, and most participants described themselves as black. Overall, the study population was healthy, with zero participants reporting emphysema and 12 reporting asthma or chronic bronchitis (Table 1). The participants provided 2949 journal entries. There were approximately 2600 responses about irritation symptoms following the 10-minutes outdoors, 2900 responses about physical symptoms experienced in the last 12 hours, and 1900 error-free measurements of lung function (eAppendix 1, http://links.lww.com/EDE/A453).

Average ambient air pollutant values are presented in eAppendix 2 (http://links.lww.com/EDE/A453). There were approximately 2700 values of H_2S and 2000 values of semivolatile PM_{10} and PM_{10}; the smaller numbers of observations for the latter 2 pollutants were due to equipment malfunction in hot and humid weather. There were approximately 1750 values for $PM_{2.5–10}$, $PM_{2.5}$, and endotoxin in the 12 communities where these pollutants were measured. Overall means, minimum and maximum community means, and between-community variation (as a % of total) are reported in eAppendix 2 (http://links.lww.com/EDE/A453). Two negative minimum community means for semivolatile PM_{10} occurred due to measurement error in the microbalance estimates of mass close to zero. More than half of the total variation in air pollutant measurements occurred between communities for 12-hour odor and 12-hour semivolatile PM_{10}. For the other measured pollutants, the majority of the variation occurred within the communities over time. This was particularly true for 1-hour and 12-hour H_2S and 1-hour and 12-hour PM_{10}, for which the between-community variances were approximately 4%, 6%, 6%, and 15%, respectively.

TABLE 2. Logistic Fixed Effects Models of Hog Odor, Hydrogen Sulfide, Nonvolatile PM_{10}, and Semivolatile PM_{10} as Predictors of Acute Irritation Symptoms Reported Immediately After Participants Spent 10 Minutes Outdoors[a]

	Twice-daily Odor			1-h Average H_2S per 1 ppb			1-h Average PM_{10} per 10 $\mu g/m^3$			1-h Average Semivolatile PM_{10} per 10 $\mu g/m^3$		
	β	SE	χ^2	β	SE	χ^2	β	SE	χ^2	β	SE	χ^2
Eye irritation	0.53	0.06	87.49	0.15	0.06	6.10	0.36	0.11	10.12	0.16	0.27	0.37
Nasal irritation	0.65	0.05	151.68	0.08	0.03	6.83	−0.00	0.04	0.00	−0.11	0.22	0.23
Throat irritation	0.41	0.06	41.75	0.12	0.07	2.49	−0.03	0.05	0.33	0.26	0.33	0.65
Skin irritation	0.37	0.16	5.56	0.13	0.25	0.26	0.56	0.38	2.17	0.47	0.93	0.26
Cough	0.25	0.07	11.89	0.14	0.12	1.34	−0.02	0.11	0.05	−0.48	0.41	1.32

[a]All models are adjusted for time of day (AM/PM).
SE indicates standard error; PM, particulate matter.

TABLE 3. Linear and Logistic Fixed Effects Models of 12-hour Average Hog Odor, Hydrogen Sulfide, Nonvolatile PM_{10}, and Semivolatile PM_{10} as Predictors of Lung Function and 12-hour Symptoms[a]

	12-h Average Odor			12-h Average H_2S per 1 ppb			12-h Average PM_{10} per 10 $\mu g/m^3$			12-h Average Semivolatile PM_{10} per 10 $\mu g/m^3$		
Lung Function												
Linear Models	β	SE	t	β	SE	t	β	SE	t	β	SE	t
PEF	−0.52	(1.58)	−0.33	−0.46	(0.71)	−0.65	1.29	(1.17)	1.10	−7.39	(4.87)	−1.52
FEV_1	−0.02	(0.01)	−1.67	−0.01	(0.01)	−1.43	−0.00	(0.00)	−0.22	−0.04	(0.04)	−1.04
Symptoms												
Logistic Models	β	SE	χ^2	β	SE	χ^2	β	SE	χ^2	β	SE	χ^2
Respiratory												
Runny nose	0.27	(0.10)	7.29	0.29	(0.09)	10.00	−0.10	(0.10)	1.00	0.35	(0.37)	0.91
Mucus or phlegm	0.19	(0.14)	1.91	0.07	(0.09)	0.65	−0.22	(0.13)	2.67	−0.44	(0.47)	0.90
Sore throat	0.08	(0.11)	0.56	0.03	(0.04)	0.39	−0.25	(0.13)	3.54	−0.24	(0.40)	0.38
Cough	0.36	(0.15)	5.50	0.09	(0.10)	0.80	0.02	(0.10)	0.02	−0.45	(0.45)	1.01
Wheezing	0.18	(0.16)	1.36	0.09	(0.06)	2.40	0.16	(0.11)	2.33	0.20	(0.56)	0.13
Difficulty breathing	0.50	(0.15)	11.18	0.33	(0.13)	7.06	0.05	(0.08)	0.50	1.22	(0.39)	9.99
Chest tightness	0.12	(0.12)	1.11	−0.01	(0.09)	0.02	0.01	(0.09)	0.02	0.53	(0.37)	1.99
Irritation												
Burning eyes	0.32	(0.10)	10.12	0.19	(0.07)	6.29	0.01	(0.09)	0.03	0.10	(0.43)	0.06
Itching eyes	0.17	(0.10)	2.71	0.12	(0.05)	5.15	0.05	(0.10)	0.26	0.01	(0.44)	0.00
Nasal irritation	0.46	(0.13)	13.67	0.12	(0.04)	7.90	0.00	(0.07)	0.00	−0.17	(0.39)	0.20
Gastrointestinal												
Nausea	0.21	(0.17)	1.59	0.18	(0.13)	1.82	−0.08	(0.17)	0.22	0.02	(0.59)	0.00
Diarrhea	−0.10	(0.28)	0.14	−0.05	(0.24)	0.04	−0.27	(0.30)	0.81	−0.46	(0.83)	0.30
Poor appetite	−0.03	(0.29)	0.01	−0.25	(0.34)	0.54	0.51	(0.20)	6.24	−0.05	(0.61)	0.01
Neurological												
Headache	0.12	(0.12)	1.00	−0.07	(0.09)	0.60	−0.03	(0.11)	0.09	0.32	(0.32)	0.96
Dizziness	0.11	(0.10)	1.25	0.06	(0.07)	0.88	0.15	(0.11)	1.92	−0.14	(0.34)	0.17
Other												
Aching joints	−0.01	(0.13)	0.01	−0.05	(0.13)	0.14	0.09	(0.07)	1.60	−0.93	(0.47)	3.84
Difficulty hearing	−0.16	(0.23)	0.51	−0.91	(0.64)	2.03	0.17	(0.11)	2.62	1.78	(0.65)	7.47
Fever	−0.02	(0.53)	0.00	0.65	(0.41)	2.48	−0.07	(0.38)	0.03	−3.32	(1.91)	3.04
Backache	−0.16	(0.14)	1.25	−0.04	(0.09)	0.17	0.13	(0.07)	3.03	−0.23	(0.39)	0.35

[a]All models are adjusted for time of day (AM/PM).
SE indicates standard error; PEF, peak expiratory flow; FEV_1, forced expiratory volume in the first second; PM, particulate matter.

Associations of acute irritation symptoms with twice-daily (10-minute) odor reports and 1-hour average pollution levels are presented in Table 2. Irritation symptoms were elevated in association with odor and H_2S, and most coefficients were substantially greater than their standard errors. Estimates of associations between 1-hour PM_{10} and irritation symptoms were near zero for nasal and throat irritation, and cough, whereas associations were positive for eye and skin irritation. Coefficients for semivolatile PM_{10} were both positive and negative and similar in magnitude or smaller than their standard errors.

Estimates of associations of 12-hour average odor, H_2S, PM_{10}, and semivolatile PM_{10} with lung function measures and 12-hour symptom variables are presented in Table 3. Point estimates for PEF and FEV_1 are negative except for the coefficient for PM_{10} and PEF. *T* values indicate that the negative coefficients are less than or equal in value to their standard errors, the largest being for the association between odor and FEV_1.

Point estimates of associations of respiratory symptoms with odor and H_2S were positive except for the coefficient between H_2S and chest tightness (Table 3). The log odds of having experienced 4 of the 7 respiratory symptoms were positive for PM_{10} and semivolatile PM_{10}. However, most of these estimates were close to zero, with the exception of difficulty breathing and 12-hour mean semivolatile PM_{10}. Additionally, sore throat symptom reports were negatively associated with increases in PM_{10}.

We observed positive associations (with high χ^2 values) of irritation symptoms in the past 12 hours with 12-hour mean odor and with 12-hour mean H_2S (Table 3). Twelve-hour irritation symptoms were not associated with 12-hour mean PM_{10} or semivolatile PM_{10} (Table 3). Overall, we found little association between gastrointestinal symptoms and 12-hour mean odor, H_2S, PM_{10}, or semivolatile PM_{10}, with the exception of a positive association between PM_{10} and poor appetite. We found little evidence of associations between neurologic symptoms and 12-hour mean odor, H_2S, PM_{10}, or semivolatile PM_{10}. Point estimates for the symptoms in the "other" category varied in magnitude and direction. Eleven of the 16 point estimates were negative, although most had very small χ^2 values. The highest χ^2 values were for the relationships of aching joints and difficulty hearing with 12-hour mean semivolatile PM_{10}, although the estimates were in opposite directions (-0.93 ± 0.47 and 1.78 ± 0.65, respectively).

Twelve-hour average concentrations of $PM_{2.5–10}$, $PM_{2.5}$, and endotoxin were modeled as predictors of lung function and 12-hour symptoms in the 12 communities with results from the sequential air sampler (n = 70 participants, Table 4). *T* values for beta coefficients from linear conditional fixed effects models were small except for the association between $PM_{2.5}$ and FEV_1; FEV_1 decreased 0.04 ± 0.02 L per 10 $\mu g/m^3$ increase in 12 hour mean $PM_{2.5}$.

Associations between symptoms and pollutants measured by the sequential sampler in the 12 communities with these measurements are also presented in Table 4. Most χ^2 values were small, indicating that these exposure measures were poor predictors of symptoms. High χ^2 values were observed for associations between $PM_{2.5–10}$ and 3 symptoms, $PM_{2.5}$ and 5 symptoms, and endotoxin and 3 symptoms. $PM_{2.5–10}$ was negatively associated with chest tightness and nausea and positively associated with aching joints. Symptoms showed more consistently positive associations with $PM_{2.5}$ (wheezing, difficulty breathing, burning eyes, nasal irritation, backache) and endotoxin (sore throat, chest tightness, nausea).

The models reported in Tables 2–4 were also fit using random effects mixed models and produced very similar results.

DISCUSSION

Concerns about air pollution from animal production facilities have grown with the global industrialization of food animal production.[1,10–14,27,28] Concentrated hog feeding operations release air pollutants from confinement buildings, manure holding pits, and land-application of animal wastes.[1,29,30] Although cross-sectional studies have documented relationships of proximity to hog operations with physical symptoms[10–14,31,32] and with reduced FEV_1,[14] they have lacked air pollution measures and most have depended solely on participant recall of symptoms over time periods of 6–12 months. The present study contributes to the literature by linking twice-daily symptom reports and lung function measurements of people residing near hog operations with physical measures of ambient air pollutant concentrations.

Several limitations should be considered in interpreting the results of this study. First, although we have repeated measures for each participant, the number of people in the study is small. The small sample size contributes to imprecision of measures of association and also limits our ability to quantify variability in measures of association between subgroups.

Several factors may limit the external validity of the study findings. The 16 study communities are not a random sample of eastern North Carolina, and we are not able to evaluate the extent to which the characteristics of air pollutants or the volunteers in the study are representative of other populations living near industrial hog operations. Furthermore, participants were nonsmoking volunteers, mostly free of chronic respiratory diseases. Associations between hog operation pollutants and health outcomes may be different among smokers and people with asthma or other conditions that increase responsiveness to pollutants. About three-fourths of the study participants reported growing up around livestock, which has been associated with lower levels of atopy in some studies.[33–35] We did not measure atopy; however, 43% of participants who grew up on a farm reported hay fever compared with 19% of those who did not, suggesting that early exposure to livestock may not have resulted in reduced responsiveness to pollutants in this population.

TABLE 4. Linear and Logistic Fixed Effects Models of Coarse Particles, Fine Particles, and Endotoxin as Predictors of Lung Function and Symptoms[a]

	12-h $PM_{2.5–10}$ per 10 $\mu g/m^3$			12-h $PM_{2.5}$ per 10 $\mu g/m^3$			12-h Endotoxin per 10 EU/mg		
				Lung Function					
Linear Models	β	SE	t	β	SE	t	β	SE	t
PEF	1.96	(2.08)	0.94	−0.19	(2.64)	−0.07	0.23	(0.45)	0.53
FEV_1	0.01	(0.02)	0.52	−0.04	(0.02)	−2.12	0.00	(0.00)	0.37
				Symptoms					
Logistic Models	β	SE	χ^2	β	SE	χ^2	β	SE	χ^2
Respiratory									
Runny nose	−0.16	(0.24)	0.46	0.13	(0.20)	0.39	0.02	(0.04)	0.41
Mucus or phlegm	−0.02	(0.15)	0.02	−0.18	(0.28)	0.40	−0.01	(0.05)	0.08
Sore throat	−0.50	(0.52)	0.91	−0.30	(0.25)	1.45	0.10	(0.05)	3.46
Cough	−0.70	(0.51)	1.89	0.01	(0.29)	0.00	0.03	(0.05)	0.33
Wheezing	0.19	(0.26)	0.55	0.84	(0.29)	8.64	−0.01	(0.06)	0.02
Difficulty breathing	−0.62	(0.42)	2.17	0.50	(0.24)	4.37	0.06	(0.05)	1.47
Chest tightness	−0.84	(0.45)	3.56	0.02	(0.24)	0.00	0.09	(0.04)	6.42
Irritation									
Burning eyes	0.15	(0.20)	0.55	0.61	(0.22)	7.78	0.02	(0.04)	0.25
Itching eyes	−0.08	(0.18)	0.21	0.38	(0.24)	2.53	0.03	(0.04)	0.72
Nasal irritation	−0.03	(0.14)	0.07	0.48	(0.25)	3.66	0.00	(0.04)	0.01
Gastrointestinal									
Nausea	−1.43	(0.71)	4.06	−0.09	(0.32)	0.07	0.10	(0.05)	3.64
Diarrhea	−1.11	(1.21)	0.85	−0.07	(0.45)	0.02	0.04	(0.10)	0.12
Poor appetite	0.62	(0.90)	0.47	−0.25	(0.62)	0.16	−0.03	(0.10)	0.08
Neurological									
Headache	−0.31	(0.39)	0.61	−0.18	(0.22)	0.63	0.06	(0.05)	1.74
Dizziness	−0.54	(0.46)	1.40	−0.26	(0.23)	1.29	0.04	(0.05)	0.77
Other									
Aching joints	0.30	(0.15)	3.99	0.02	(0.24)	0.01	0.00	(0.04)	0.01
Difficulty hearing	−0.10	(0.43)	0.05	0.53	(0.41)	1.70	0.04	(0.07)	0.41
Fever	0.18	(0.95)	0.04	−0.64	(0.79)	0.67	0.19	(0.14)	1.96
Backache	−0.02	(0.15)	0.01	0.61	(0.25)	5.86	0.03	(0.04)	0.60

[a]All models are adjusted for time of day (AM/PM).
SE indicates standard error; PEF, peak expiratory flow; FEV_1, forced expiratory volume in the first second; PM, particulate matter.

The air-monitoring equipment for this study was large and difficult to conceal. In some communities, participants reported reductions in hog odor and spraying of hog waste during the study compared with time periods before and after the equipment was in their neighborhoods. Changes in waste management practices could have lowered exposure levels during the study, and consequently our ability to detect effects. In addition, exposure variability within communities could not be quantified by the stationary, centrally located monitors.

Finally, lung function data were of lower quality and were less complete than other outcome data.[21] Lung function assessment depends upon proper technique and is ideally conducted by a laboratory technician.[36] In this study, participants were trained to make 3 measurements to the best of their ability each time they collected data. Given the community-based setting, we did not feel it was appropriate to apply American Thoracic Society/European Respiratory Society standards to these measurements.[37] Instead, we analyzed only error-free readings, further reducing sample size and the precision of estimates of association. Therefore, it is of interest that a 10 $\mu g/m^3$ increase in $PM_{2.5}$ (measured only in 12 of the 16 communities) was associated with a 0.04 ± 0.02 L decrease in FEV_1 ($T = -2.12$).

Despite these limitations, most exposure-outcome relationships were in the predicted direction; most of those not in the predicted direction were weak. We observed unexpected negative associations between PM_{10} and sore throat, $PM_{2.5–10}$ and nausea and chest tightness, and semivolatile PM_{10} and aching joints. We are not aware of any biologic mechanisms whereby these air pollutants or unmeasured copollutants could protect against development of these symptoms. Although the study design and analytic methods preclude confounding by time-invariant characteristics of participants, these negative associations could reflect uncontrolled time-related confounding, measurement error, or both.

In addition, our findings were generally consistent with prior studies of airborne emissions from industrial hog operations. For example, in a controlled experiment, 48 healthy adult volunteers (mean age = 26) reported eye irritation and nausea more frequently when exposed to diluted swine air than when exposed to clean air.[38] Radon et al[14] found evidence of decreased FEV_1 and increased wheezing in association with the number of concentrated animal feeding operations near participants' residences, and increased reports of asthma and nasal allergies in association with reported annoyance with odor. Mirabelli et al[12] observed a 23% higher prevalence of wheezing among children who attended schools where staff reported livestock odor inside school buildings twice or more per month, compared with schools where no livestock odor was reported. In a cross-sectional study of rural Iowa children, living on a farm that raised swine and added antibiotics to animal feed was associated with asthma-related outcomes.[11] Finally, endotoxin exposures have been associated with increased respiratory and systemic symptoms and decreased lung function,[39] and working in hog operations has also been associated with respiratory symptoms, reduced lung function, and organic dust toxic syndrome.[15,16,40,41]

Interestingly, in contrast to some other studies, we did not observe an association between hog operation air pollutants and headaches.[10,38,42] It is possible that headaches are more prevalent among individuals living near hog operations, but that the incidence of headaches does not covary with odor and pollutants on the short-time scale used in our study. Although an acute association with headache was observed in a chamber study,[38] that exposure was diluted air from a swine confinement building, and the experimental subjects were naive volunteers who did not live near hog operations.

Among the pollutants we measured, H_2S (which is produced by anaerobic decomposition of sulfur-containing organic matter in hog waste pits[1]) provides a fairly specific measure of hog operation pollution in these rural areas where there are few other industrial sources of H_2S. In contrast to H_2S, PM is a ubiquitous air pollutant with many sources and has been previously associated with lower lung function, heart rate variability, and mortality.[43–46] In addition to solid particle sources, constituents of PM may form indirectly in the atmosphere through reactions of precursor gases such as NH_3[47] to form soluble substances such as ammonium nitrate.[48] These particles may be semivolatile, in equilibrium between gas and particle phases,[49] and may have different effects than nonvolatile fractions of PM. Therefore observed associations between PM, symptoms, and lung function could be due to PM emitted by hog operations, PM from other sources, or both. We were specifically interested in $PM_{2.5–10}$ because of the possibility that hog dander, feed, dried feces, endotoxin, and other microbial matter would be present in the coarse fraction.[30] However, of all the pollution measures, $PM_{2.5–10}$ showed the smallest and least precise associations with symptoms and lung function.

Conclusions

This longitudinal study contributes to evidence obtained from cross-sectional research that suggests that air pollutants near hog operations cause acute physical symptoms, particularly upper respiratory symptoms and irritation of the nose and eyes. Despite limitations of measurements of exposure and outcome, the temporal nature of the analysis eliminates confounding from time-invariant factors and strengthens the evidence. Adjustment for time of day helps reduce any time-related confounding that could be introduced by diurnal covariation in symptoms and air pollutants. Variability in pollutants within morning and evening periods is large enough so that overadjustment is not a concern.

Industrial hog operations in North Carolina are disproportionately located in low-income communities of color[10,29] where there is more potential for exposure to outdoor air pollutants due to older homes that are not air tight and have no air conditioning. Many residents also lack the financial resources to travel and choose activities that could help them avoid high pollution. Exposure to air pollution from hog operations is an environmental injustice in rural areas hosting facilities that supply pork to populations spared the burdens of its production.

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Exhibit 11 to the Declaration of Professor Steven B. Wing, Ph.D.

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IMPACT OF ODOR FROM INDUSTRIAL HOG OPERATIONS ON DAILY LIVING ACTIVITIES*

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ABSTRACT

Intensive industrial animal production systems worldwide require confinement of large numbers of animals in small spaces and concentration of enormous quantities of waste. Industrial hog operations, in particular, have raised public concerns about their adverse impact on public health and sustainable development. Using a community-based participatory research approach and qualitative interviews, we explored people's perception of the impact of odor from these industries on daily living activities as they relate to the beneficial use of property and enjoyment of life. Our research indicates that hog odor limits several leisure time activities and social interactions which could have adverse public health consequences. The results of this study can assist the communities and other stakeholders in public policy development that addresses these concerns.

Worldwide, livestock production systems are changing from small farms to intensive industrial production systems [1]. In the case of pigs, significant

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concentrations have developed in areas where access to corn and soybean by-products are available for animal feed, as in the Netherlands, or in regions where government policies and vertical integration have resulted in rapid growth, for example, in North Carolina [2]. In the U.S, which ranks third in pig meat production (9.3 million metric tons annual production) after the People's Republic of China (48.3 million metric tons) and the European Union with 25 member states (21.6 million metric tons), approximately 79% of the 62 million hogs produced annually comes from medium or large corporate facilities [3]. North Carolina, the location of this study, rose from the country's fifteenth- to its second-largest pork-producing state in less than two decades [3], with a rapid shift from small family farms to large-scale corporate production.

In contrast to traditional small farms, industrial production systems involve large concentrations of animals in confined spaces and the generation of enormous quantities of solid, liquid, and gaseous wastes in small geographic areas. In North Carolina, they are disproportionately concentrated in communities of color and/or low-income communities, resulting in environmental injustices and disproportionate exposure to environmental and public health risks [4-7]. Adverse impacts of pollution from hog waste have been examined on ground and surface waters [8-11], economic and employment development [12, 13], devaluation of land and properties [14, 15], respiratory and other health problems, and quality of life [4, 16-19].

However, the effect that concentrated hog waste and odor have on people's daily activities related to beneficial use of property and quiet enjoyment of life requires in-depth exploration. Enjoyment of life and beneficial use of property are two of the components considered in defining a nuisance. A nuisance is generally defined as a use of property or an activity that unreasonably limits or diminishes a person's health, safety, or enjoyment of life; or that interferes with the other person's quiet enjoyment or beneficial use of his or her own property [20]. More specific to farm nuisance in North Carolina, nuisance is defined in N.C. General Statute § 7A-38.3—*Pre-litigation mediation of farm nuisance disputes,* as an action that is injurious to health, indecent, offensive to the senses, or an obstruction to the free use of property.

This article explores community members' perception of odor from industrial hog operations and its impacts on daily living activities related to the beneficial use of property and quiet enjoyment of life. Our goal is to provide public health policy recommendations associated with the built environment rather than recommendations for legal remedies. Our analysis uses data from the qualitative part of a larger community-based participatory research (CBPR) project that explored the impact of industrial hog operations (IHOs) on health and quality of life [21]. Community-based participatory research is a partnership approach to research that equitably involves community members and other stakeholders in the research process and builds on the partners' strengths [22]. Rooted in part in the revolutionary approaches to research that emerged from works with oppressed communities in Africa, South America, and Asia in the 1970s [23-25], in some respects, CBPR is considered an orientation to research rather than a particular research method [26]. Under this conception, CBPR addresses health from a broad ecological perspective and engages the community in the research process in a manner that is participatory and builds community capacity [22, 27, 28] without creating colonial relationships between research institutions and lay communities. It integrates local and academic or professional knowledge and expertise and focuses on community-driven issues and actions to improve health as part of the research process.

METHODS

Two series of in-depth interviews were conducted with 75 participants in eastern North Carolina in 2002 and again in 2004 and 2005. Participants were adults (18 years or older) who lived near industrial hog operations and were willing to be interviewed. The first series of interviews was conducted with a convenience sample of 26 participants. The results from these interviews were used to guide the development of a study instrument for a second series of semi-structured open-ended interviews. In this series, 34 interviews were conducted with 49 additional participants from 16 neighborhoods and communities. Some interviews were with couples in the same household. Forty-two of the 49 interviewees also participated in a quantitative longitudinal study exploring the impact of hog odor on health prior to their interview. All participants lived within 1.5 miles of one or more hog operations and were non-smokers. The interviews were conducted in the homes of participants and lasted between 30 minutes and two hours. Informed consent and written permission to audio record the interviews were obtained prior to the start of the interviews. A pair of interviewers, consisting of one academic and one community organizer, conducted each interview.

In addition to information on basic demographic characteristics (age, gender, and race), data were collected about context, experience, beliefs and attitudes, coping mechanisms, capabilities, and individual and/or collective actions as they related to hog odor. Table 1 provides a summary of the general categories and rationale for the questions that were explored during the interviews.

Interviews were audiotaped and transcribed, and an evolving list of codes was developed for all interviews by two members of the research team using grounded theory approach [29-31]. During the initial steps of analysis, interview texts were thoroughly read and passages were first open coded and then categorized according to relevant research questions and a code book was created based on axial coding. Open coding involves forming initial categories of information and assigning codes by segmenting the text; in axial coding, data are assembled based on a coding paradigm [31]. Initial validation of the codes

Table 1. Categories and Questions Explored in In-Depth Interviews

Category	Purpose	Questions
Context	To explore social and physical environment	• Do you consider yourself living in a community? If yes, what makes it a community to you? • What do you like about your community? Why? • What do you dislike about your community? Why?
Experiences and their meanings	To explore emotions, feelings, beliefs, and meta-beliefs	• What was it like for you growing up? • What are/were some activities you enjoy doing? • What do/did those activities mean to you? • What are/were some activities you enjoy doing but you no longer do? Why?
Coping mechanism	To explore attitudes and responses to hog odor	• What do you do when the odor comes? [Probe: 1) what are specific lifestyle changes that are related to hog odor? 2) What are specific actions (social and political) taken that are related to hog odor?]
Recognizing capabilities	To create ongoing reflection in participants about looking into realities and 1) *recognizing* something they might want to have but do not currently have e.g., a voice in decision-making process); 2) *understanding* the implications of not having this capability when faced with other similar problems; 3) creating a new ability to fill this void.	• What do you think can be done about the odor? • What role do you think you and/or other community members could play in addressing the problem? (Why or why not?) • What (resources) would you (or others) need to be able to do this?

was undertaken by reviewing and discussing the formulated descriptions and categories of themes with key informed community partners. The second validation step was undertaken by returning to 12 of the 49 participants in the original 34 interviews. To ensure these participants had an equal chance of being selected for the second validation step, we randomly selected 10 of 34 interviews using Random Generator for Microsoft Excel software and conducted the validation sessions with their respective participants. Two participants were lost to follow up and the final validation sessions occurred with eight of the 10 randomly selected interviews. During these validation sessions, the participants were presented with the codes and the transcription of their statements that corresponded with those codes and asked to verify if the codes accurately depicted what they had said during their in-depth interviews.

The questions explored in this article are: From the perspective of the participants, what is beneficial use of property and how does hog odor interfere with those uses? From the perspective of the participants, what is enjoyment of life and how does hog odor interfere with that? What is the extent of the interference in terms of time and place?

RESULTS

Sixteen neighborhoods and communities where the participants lived are located in three counties in eastern North Carolina and have high concentrations of industrial hog operations. Demographic characteristics of interview participants are summarized in Table 2.

Table 2. Demographic Summary of the Participants

Category	No. (%)
Number of participants	49
Number of interviews	34
Number of Black participants	43 (87.8%)
Number of White participants	6 (12.2%)
Number of female participants	32 (65.3%)
Number of male participants	17 (34.7%)
Hours of interview	34 hours, 11 min
Average age of participants	57 years
Age range (in years)	32-84

Data obtained from the U.S. Census Bureau [32] indicated that African Americans constituted from greater than 45% to nearly 90% of the people living in these communities at block group levels. At the time of the interviews, all participants in our study owned their homes and, with the exception of two participants who had lived in the community for fewer than five years, they had been born and raised or had lived in their respective communities most of their lives. More than half of the participants lived on a land that had been in their family for more than one generation. Most participants had lived on or near a farm and were familiar with odor from non-industrial hog farms. Qualitative description of the participants about the proximity of their homes to one or more hog operations showed that the hog facilities and/or their spray fields (spray fields are open fields where liquified hog waste is sprayed using large sprinkle systems) were quite visible and sometimes the sprayfields extended to the participant's "door step" and "driveway" or they were located "down the road." All participants lived within a 1.5-mile radius of a hog facility, which was one of the criteria for participation in the larger exposure study.

Examples of participants' significant statements about activities of daily living that related to and were coded as "beneficial use of property" and "quiet enjoyment of life" included working outside, growing vegetables, sitting outside, eating outside, gardening, playing, barbequing, use of wellwater, sleeping, opening doors and windows, hanging out with neighbors, having family and guests over, and drying laundry among others. They are presented in Tables 3 and 4, respectively, along with the examples of statements about the impact of hog odor on those activities.

These were recurring themes in almost all interviews with differences in participants' qualitative description of how the hog odor schedule, duration, and intensity affected these activities in terms of time of day, frequency, and duration. The impact of hog odor on these activities occurred among all participants with some participants not engaging in those activities "any more" or "as often as they used to," or scheduling those activities around hog odor's "schedule" and/or "intensity" to those who would interrupt what they were doing and "go inside when the odor comes." Participants used words and phrases such as "bad," "terrible," "it just stinks," or "you can't stand it" to qualify the odor and explained when the odor comes, they will "go inside," "lose appetite," or "stop doing what [they] are doing and go inside." Activities that participants did not engage in "any more" were mostly social activities such as family reunions and having guests over to avoid embarrassment and shame due to the possible untimely arrival of hog odor. Two participants reported that the hog odor did not interfere with their beneficial use of property as illustrated in the following direct quote: "Health problems have not affected me . . . a lot of people are experiencing serious respiratory problems though . . . with myself, I continue to do things outside . . . I know there are communities much worse than the one that I live in." In terms of adverse environmental and economic impacts, hog odor was

Table 3. Examples of Participants' Significant Statements about Beneficial Use of Property

Beneficial use of property (BUP)	Hog odor interference with BUP
1. Sit outside	1. Can't sit outside
2. Eat outside	2. Can't have guests over
3. Cook out	3. Can't have cookouts
4. Barbeque	4. Can't have family reunions
5. Dry laundry	5. Can't play outside
6. Have guests over	6. Can't garden
7. Open windows/doors to air the house	7. Can't hang out with neighbors
8. Fresh clean air	8. Can't keep working outside with odor
9. Open window at night [for cool air]	9. Devaluation of property
10. Sleep	10. Unpredictability of odor
11. Garden	11. Can't use well water
12. Play outside [children]	12. Buy bottled water
13. Family reunion on property	13. Had to get and use air conditioner
14. Hang out with neighbors	14. Had to buy a dryer
15. Grow own vegetables	15. Have a hard time sleeping or wake up at night
16. Use well water for drinking	

Examples of participants' statements related to beneficial use of property

"The beautiful landscape that we have here and the animals roaming about. And you could just walk out, you could just sit outside and enjoy in the summertime."

"He [child in the family] likes to go outside. He likes to play basketball."

Examples of participants' statements related to hog odor interference

"You wouldn't invite a person over for a cookout on your deck if you expected hog odor to come in."

"I only had one cookout. One cookout [repeated for emphasis by the participant]. That has changed because I don't invite people over because I don't want them to come in and smell that odor."

"Couldn't invite people over for a cookout, family reunion."

"I had my uncle, my grand daddy, I had my grandma before she died. A lot of my family come and can't stay here. They say, 'god, I can't stand this. How can you live here?'"

"My son has asthma and allergies . . . he just stays inside."

"I had a rose garden . . . do you see those weeds there . . . I haven't done it for the past few years. . . ."

"Sometimes it's so unbearable you couldn't even hardly stand it, not even in the house."

"On a bad day it is not that you can't go outside . . . but the odor determines how long you gonna stay . . ."

"When the smell [hog odor] get in, you can't get rid of it."

"They went up so much that we went in to talk to him. And I had stuff here in writing saying that the property has gone down 20-30 percent because you are near a hog farm."

"It [the odor] could come any time, day or night . . . mostly at night was worse."

"The water turns everything yellow. If I wash my clothes for a good six weeks in that water, I will have to buy new clothes . . . I will have to buy new clothes every six weeks."

"I don't drink the ground water no more because of the hog farms . . . now we have to buy water to drink."

"It [hog odor] woke me up. And I had to get up. I couldn't sleep. I put the covers up over my face and it didn't do any good."

Table 4. Examples of Participants' Significant Statements about Quiet Enjoyment of Life

Quiet Enjoyment of Life (QEL)	Hog odor interference with QEL
1. Enjoy being outside	1. Staying outside
2. Enjoy working outside	2. Socializing
3. Enjoy visiting with neighbors	

Examples of participants' statements related to Quiet Enjoyment of Life:

"We enjoyed the outdoors. That was the main spot. Sitting in the house was not our thing."

"We would get together as a community and do a lot of things."

"I used to like to go outside for walks and breathe fresh air."

"I love to sit on my porch when possible . . . and I will sit out there as long as I can."

"I enjoy gardening . . . woodworking."

"A lot of times when I get home from work . . . like to go outside to visit with neighbors . . . play ball."

"You take away outside for anyone living in the country, to a degree they will cease living."

"We grew up loving the outdoors and now it is a part of us. So when we get together, we still do things outside"

Examples of participants' statements related to hog odor interference

"I had to pay money to buy this place. Why can't I go sit outside and enjoy?"

"I've been in this spot all my life. When me, my mom and my dad first lived here before the hogs . . . we could stay outside late at night until 10-11 o'clock and you couldn't smell anything but ever since the hogs came in we couldn't go out there anymore . . . everybody in the neighborhood used to go to each other's houses and sit outside and enjoy it but now it's just so bad."

". . . we used to stay outside or play late at night or we would cook out at night cuz everyone could sit out there around the trees and have a fire . . . like a family we would but we can't do that anymore because of the smell."

"I used to enjoy walking back and forth down the road . . . but I just won't go outside anymore . . . the flies are so bad . . . the smell is so bad."

"It's really hard to let the kids go out and play even . . . you know if you want to go out and wash the car, sit at the picnic table and even something so simple as sitting on the porch, we just don't enjoy doing those kinds of things because we just never know when he is going to spray. Or if we do go try to enjoy those types of things and we see him pass by . . . nine times out of ten he will go turn those sprayers on . . . and that is absolutely what he does."

mentioned as the reason to buy a dryer (to dry laundry), to install or use air conditioning, and to pay to discontinue the use of well water and use bottled water or get connected to city water.

DISCUSSION

Integrating the results from the analysis of "beneficial use of property" and "quiet enjoyment of life," our research shows that hog odor limits activities of daily living that participants either "enjoyed" doing the most or expected to be able to perform inside and outside their homes. It restricts, for instance, activities like cookouts, barbequing, family reunions, socializing with neighbors, gardening, working outside, playing, drying laundry outside, opening doors and windows for fresh air and to conserve energy, use of well water, and growing vegetables. When we examine these restrictions in terms of types of activities and in the context of our area of study, which includes low-income rural communities with a high percentage of African Americans, the cumulative adverse impact goes beyond mere violation of property rights and has critical public health ramifications.

The types of activities that are restricted by hog odor are social interactions, physical activities, energy- and cost-saving activities, relaxing outside or indoors, and sleeping. Social activities have been shown to positively affect health, improve overall well-being, reduce stress, and strengthen social networks [33-35].

Furthermore, activities like gardening, working, growing vegetables, and playing outside, naturally integrate physical activity into the day-to-day living of rural residents and have enormous health benefits. Research has already shown that residents in rural communities perceive the environmental barriers as a reason for physical inactivity [36, 37]. Therefore, any moderate to severe restriction in these activities could further force the rural residents into an inactive and sedentary lifestyle. In fact, a study published in 2005 by Martin et al. [38] based on a nationwide survey about physical activity in the U.S. revealed that physical **in**activity (PIA) levels were higher in rural areas than in urban areas and that, regionally, the urban-rural differences were most striking in the South. It is estimated that physical inactivity and diet contribute to approximately one-third of all cancers [39]. These statistics are even more alarming for low-income populations and people of color who are at particularly high risk for several chronic diseases [40-41], have limited access to health care [43, 44], and limited means to seek regular treatment for their illnesses [45-47].

Current regulations and enforcement mechanisms for industrial swine operations do not adequately protect public health. Improvements could be brought about by considering their cumulative impacts on the physical, mental, and social well-being of residents of neighboring communities. Policy recommendations published by Donham et al. in 2007 [48] could help to address these impacts. They include, among other recommendations, the issuance of permits based on the carrying capacity of the local environment and decision-making at local levels. While reiterating their policy points, we additionally recommend that:

- Requirement to include direct and indirect impacts on quality of life and activities of daily living in environmental and public health impact statements for all existing and new concentrated animal feeding operations should be required.
- For existing operations, specific timelines could be mandated for evaluating these issues and implementing necessary protections.
- Strong support for sustainable farming practices and independent farmers.

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Exhibit 12 to the
Declaration of Professor Steven B. Wing, Ph.D.

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Source tracking swine fecal waste in surface water proximal to swine concentrated animal feeding operations

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HIGHLIGHTS

- We studied the sanitary quality of surface water proximal to swine CAFOs.
- Fecal indicator bacteria levels suggest poor water quality proximal to swine CAFOs.
- Swine-specific Bacteroidales were more prevalent proximal down- vs proximal upstream.
- Swine-specific Bacteroidales can help track fecal waste proximal to swine CAFOs.

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ABSTRACT

Swine farming has gone through many changes in the last few decades, resulting in operations with a high animal density known as confined animal feeding operations (CAFOs). These operations produce a large quantity of fecal waste whose environmental impacts are not well understood. The purpose of this study was to investigate microbial water quality in surface waters proximal to swine CAFOs including microbial source tracking of fecal microbes specific to swine. For one year, surface water samples at up- and downstream sites proximal to swine CAFO lagoon waste land application sites were tested for fecal indicator bacteria (fecal coliforms, *Escherichia coli* and *Enterococcus*) and candidate swine-specific microbial source-tracking (MST) markers (*Bacteroidales* Pig-1-Bac, Pig-2-Bac, and Pig-Bac-2, and methanogen P23-2). Testing of 187 samples showed high fecal indicator bacteria concentrations at both up- and downstream sites. Overall, 40%, 23%, and 61% of samples exceeded state and federal recreational water quality guidelines for fecal coliforms, *E. coli*, and *Enterococcus*, respectively. Pig-1-Bac and Pig-2-Bac showed the highest specificity to swine fecal wastes and were 2.47 (95% confidence interval [CI] = 1.03, 5.94) and 2.30 times (95% CI = 0.90, 5.88) as prevalent proximal down- than proximal upstream of swine CAFOs, respectively. Pig-1-Bac and Pig-2-Bac were also 2.87 (95% CI = 1.21, 6.80) and 3.36 (95% CI = 1.34, 8.41) times as prevalent when 48 hour antecedent rainfall was greater than versus less than the mean, respectively. Results suggest diffuse and overall poor sanitary quality of surface waters where swine CAFO density is high. Pig-1-Bac and Pig-2-Bac are useful for tracking off-site conveyance of swine fecal wastes into surface waters proximal to and downstream of swine CAFOs and during rain events.

1. Introduction

Hog production in the United States (US) has shifted from numerous small family farms to fewer large vertically integrated concentrated animal feeding operations (CAFOs) (MacDonald and McBride, 2009; Reimer, 2006). In North Carolina (NC) between 1991 and 1998, the number of swine increased from 3.7 million to over 10 million, placing NC as the second leading state in US pork production (Edwards and Ladd, 2000). Since 1998, NC has remained the second leading US pork producer with recent total hog and pig inventory estimates ranging mostly between 8 to 9 million (NCDACS, 2012; USDA, 2007, 2012, 2013, 2014). Swine CAFOs are disproportionately located in the eastern coastal plain region of NC (Wing et al., 2000) and house large numbers of animals whose waste is collected and stored in open-pits called lagoons before the liquid waste is sprayed onto agricultural fields.

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According to 2012 county-level estimates of the North Carolina Department of Agriculture and Consumer Services, the top five NC hog-producing counties (Duplin, Sampson, Bladen, Wayne, and Jones) are contiguous and have a population of over 5.6 million swine (NCDACS, 2012). Government officials, agricultural experts, and neighbors of swine CAFOs have expressed concern that this scale of swine production and the associated quantity of manure produced in a small area of land could lead to over-application to agricultural fields and off-site conveyance of fecal pollution and contamination of surface waters (USGAO, 2008).

The NC Department of Environment and Natural Resources (NCDENR) permits swine CAFOs as non-discharge facilities. Swine CAFO permits and regulations include nutrient management plans for the application of liquid waste according to agronomic rates of nutrient uptake of crops grown on the permitted land application spray fields (Edwards and Ladd, 2000; NCGA, 1995). However, questions remain about whether fecal pollution from swine CAFOs in NC can be conveyed off-site of permitted spray fields and whether there are impacts on the sanitary quality of surface waters proximal to swine CAFOs (Jongbloed and Lenis, 1998; Krapac et al., 2002; Thurston-Enriquez et al., 2005).

In 2012, Duplin County, NC had an estimated swine population of 2,040,000 and an estimated poultry population (broiler and other meat-type chickens as well as turkeys) of 88,500,000 (NCDACS, 2012). Because sources of fecal contamination of surface water can be diverse – with numerous potential animal and human inputs – better tools and technologies are needed to track species-specific sources of fecal wastes. Microbial source tracking (MST) methods are designed to improve the identification of sources of fecal contamination (Boehm et al., 2013; Dancer et al., 2014; EPA, 2005). Several candidate swine-specific fecal MST markers have been proposed (Mieszkin et al., 2009; Okabe et al., 2007; Ufnar et al., 2007) with variable specificity and unresolved questions about the generalizability of the markers in different geographic locations (Santo Domingo et al., 2007; Stewart et al., 2013). Application of the proposed microbial source tracking markers to help evaluate management practices in agricultural watersheds has also been limited, although studies in Ontario have used *Bacteroidales* markers to assess livestock exclusion practices (Wilkes et al., 2013) and to compare tile drainage management techniques (Wilkes et al., 2014). Determining whether candidate swine-specific fecal MST markers can be detected in environmental waters in NC, an area with high swine density, is important to assess whether these markers could be useful tools to evaluate and implement best management practices (BMPs).

In this study we aimed to evaluate the impact of swine CAFO liquid waste land application on the sanitary quality of proximal surface waters in NC. The study's specific objectives were to estimate concentrations of fecal indicator bacteria (fecal coliforms, *Escherichia coli*, and *Enterococcus*) in surface waters proximal to swine CAFO liquid waste land application spray fields and to field test candidate MST markers of swine fecal wastes in surface water samples proximal to swine CAFO liquid waste land application sites.

2. Methods

2.1. Study location

Sampling was conducted in the coastal plain region of eastern NC where there is a high density of swine, chicken, and turkey CAFOs as well as beef cattle on pasture. Swine CAFOs typically use liquid waste management systems (lagoons and spray fields), whereas most poultry CAFOs in the area use dry litter waste management systems in which waste-laden litter is applied to fields. Many rural homes in the area use septic systems for sewage disposal. Sampling locations were selected proximal upstream and proximal downstream of three swine CAFO liquid waste land application fields (Sites 1–3), where streams could be sampled from a public right-of-way. We use the letters A and B to denote proximal upstream and proximal downstream locations, respectively, at each swine CAFO surface water sampling site; however, "A"

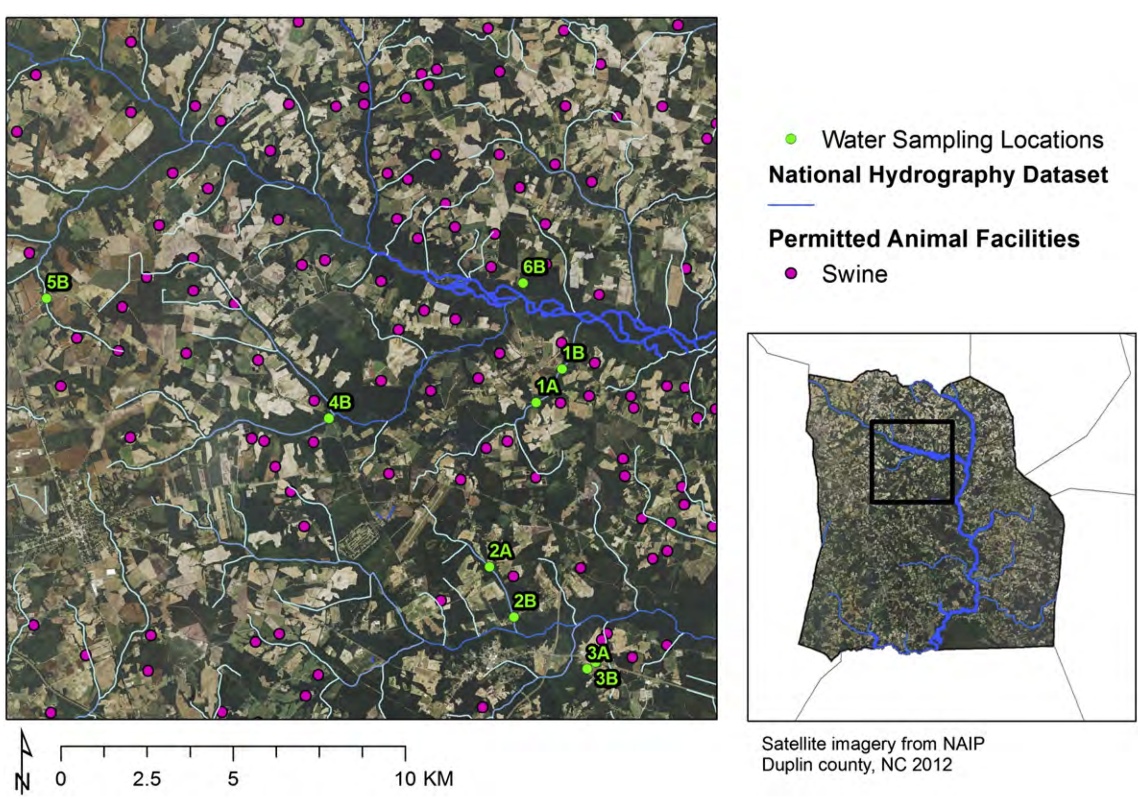

Fig. 1. Map of surface water sampling sites proximal to swine concentrated animal feeding operation spray fields, North Carolina.

sampling locations were proximal and downstream of numerous other swine CAFOs. We could not identify accessible sampling locations in the study watersheds where there were no upstream swine CAFOs.

2.2. Sample collection

A total of 187 surface water samples were collected via weekly sampling for six months (from mid-February to mid-August 2010) and monthly sampling (from mid-September 2010 to mid-January 2011) to capture seasonal trends. Surface water samples were collected from public access waters proximal to swine CAFO liquid waste land application sites (Fig. 1). Seventy six samples were collected at Site A (proximal upstream) locations and 109 at Site B (proximal downstream) locations (2 samples were missing site A/B designations). Sterile 4-liter Nalgene bottles were used for collection after they were washed and autoclaved for 15 minutes at 121 °C. Sample bottles were coded so that sample processors were blinded during laboratory analysis. After collection, samples were transported on ice. All samples were analyzed for fecal coliform bacteria within 24 hours of sample collection. Known-source fecal waste samples (swine lagoon, swine wallow-water, swine feces, and other animal feces) were collected in sterile containers and transported to the laboratory in coolers on ice for analyses. Rainfall data were obtained from a State Climate Office of North Carolina weather station within 27–47 km of the sampling locations. Hourly increments of rainfall (inches) were combined to tabulate the cumulative amount of rain (inches) that fell during the 24 and 48 hours before sampling.

2.3. Fecal indicator bacteria estimates

Fecal indicator bacteria were quantified using standard membrane filtration techniques (APHA, 2006). Fecal coliforms were quantified by membrane filtration using modified fecal coliform (mFC) agar. *Enterococcus* were quantified by EPA method 1600 using modified mE medium (mEI) containing the chromogenic substrate indoxyl-beta-D-glucoside (EPA, 2009a). *E. coli* were quantified by EPA method 1603 using modified m-TEC media (EPA, 2009b). Negative controls were included in each membrane filtration analysis. Samples were filtered in dilutions to obtain counts in the 30–300 colony forming units (CFU)/100 mL range. To test reproducibility of fecal indicator bacteria methods within the laboratory, samples were filtered in duplicate 20% of the time, or every fifth set of samples. All duplicates were within an order of magnitude of each other.

2.4. Swine fecal microbial source-tracking (MST) markers

To examine DNA in each surface water sample, 500 mL of water was filtered using a 0.22 μm Durapore® (Millipore, Billerica, MA) membrane. Excess filter paper, i.e. paper that was not exposed to the sample, was cut aseptically and discarded before placing the filter in a PowerBead tube to extract DNA using the PowerSoil™ DNA Isolation Kit (MO BIO Laboratories, Inc., Carlsbad, CA) following the manufacturer's instructions. Similarly, this kit was used to extract DNA from 0.5 g of each known-source fecal sample with use of provided PowerBead tubes, as recommended by the manufacturer. Swine lagoon and wallow water samples were collected in sterile centrifuge bottles and 250 mL of liquid were centrifuged at 3000 ×*g* for 20 minutes. The supernatant was removed to allow access to the pellet, and 0.5 g of the pellet was placed into a PowerBead tube. Instead of utilizing the MO BIO Vortex Adapter tube holder to vortex the PowerBead tubes for 10 minutes as recommended by the manufacturer, the PowerBead tubes were vortexed using the high energy Mini-Beadbeater (BioSpec Products, Bartlesville, OK) for one minute. DNA extractions were stored at −80 °C and were used for multiple PCR assays.

A series of PCR assays were performed for swine-specific markers. PCR assays for Pig-1-Bac and Pig-2-Bac were performed using a Qiagen QuantiTect Probe PCR kit and the Pig-Bac-2 and P23-2 assays were performed using 5 PRIME MasterMix with the appropriate amount of deionized water and primers according to manufacturer's instructions (Supplemental Table S1). Reactions for Pig-1-Bac and Pig-2-Bac assays were conducted in duplicate using primers and probes described by Mieszkin et al. (2009) using a Cepheid Smart Cycler model SC1000-1. Although Pig-1-Bac and Pig-2-Bac assays were run on a real-time machine quantitative results are not reported because: (1) a standard curve was not consistently run so we are not confident reporting quantitative results; and (2) we wanted to be consistent in our reporting across the assays. Reactions for Pig-Bac-2 and P23-2 assays were performed in duplicate as described by Okabe et al. (2007) and Ufnar et al. (2007), respectively. Reactions were carried out using an Eppendorf MasterCycler gradient thermal cycler; then products were visualized on a 1.5% agarose gel. All assays were performed with negative controls. An internal amplification control (IAC) for the P23-2 assay was used as described by Ufnar et al. (2007). This IAC was also tested to determine the lower limit of detection (10^{-5} μM). For the *Bacteroidales* PCR assays, extracts from a positive lagoon sample and two pig fecal samples were used as positive controls. The same samples were consistently used as positive controls, although multiple extracts were utilized from the samples over the course of the study.

A separate PCR assay using salmon sperm DNA was performed to test for inhibition in each DNA extract (Haugland et al., 2005). A known amount of salmon sperm DNA was injected into each DNA extract as well as a positive control. Duplicate PCRs were performed using a Qiagen QuantiTect Probe PCR kit in a Cepheid Smart Cycler model SC1000-1. The sample was considered inhibited if the difference of cycle threshold (C_T) between extract and control was greater than 3.3. If inhibited, the DNA extract was diluted tenfold and tested for inhibition again. Once an extract was considered to not be inhibited, it was retested for the four swine assays: Pig-1-Bac, Pig-2-Bac, Pig-Bac-2, and P23-2.

To examine the sensitivity and specificity of the four candidate swine-specific fecal microbial source-tracking markers, we tested pig fecal (n = 6), pig wallow water (n = 2), pig waste lagoon (n = 7) as well as chicken (n = 6), turkey (n = 3), goat (n = 2), cow (n = 4), horse (n = 1) and human (n = 3) fecal samples collected from sites in NC. Sensitivity of each of the four candidate swine-specific fecal microbial source-tracking markers was calculated as the proportion of known-source swine fecal samples that tested positive for each marker. Specificity was calculated as the proportion of known-source non-

Table 1
Fecal coliform, *E. coli*, and *Enterococcus* concentrations (CFU/100 mL) in surface waters at A and B sites proximal to swine concentrated animal feeding operation spray fields in North Carolina.

	Fecal coliforms (CFU/100 mL)				*E. coli* (CFU/100 mL)				*Enterococcus* (CFU/100 mL)			
	N	Range	Geo. mean	*p*-Value[a]	N	Range	Geo. mean	*p*-Value[a]	N	Range	Geo. mean	*p*-Value[a]
All A sites 1–3	76	0.5, 9091	111		76	0.4, 2090	78		75	1, 8517	89	
All B sites 1–3	76	0.5, 140,000	187	0.09	76	1, 5400	106	0.22	75	1, 10,400	103	0.64
All B sites 4–6	33	10, 117,273	331	–	33	10, 3167	121	–	33	10, 4267	220	–

Note. Site A = proximal upstream sampling location. Site B = proximal downstream sampling location. CFU = colony forming unit.
[a] T-test statistic from fixed-effects generalized linear regression model to account for repeated measures at each site.

swine fecal samples (i.e., chicken, turkey, goat, cow, horse, human) that tested negative for each marker.

2.5. Statistical analysis

Descriptive statistics were calculated for each of the fecal indicator bacteria estimates in surface water. T-test statistics were estimated using conditional fixed-effects linear regression models to account for repeated sampling at each site (Allison, 2005). Estimates of the concentration of each fecal indicator bacteria were compared to recommendations set by the North Carolina Department of Environment and Natural Resources (DENR) Division of Water Quality (DWQ) "Redbook" (NCDENR, 2007) and the United States Environmental Protection Agency (EPA) recreational water quality guideline values (EPA, 2012). We calculated the proportion of samples that exceeded state (NCDENR, 2007) and federal (EPA, 2012) recreational fresh water quality guideline values by tabulating the number of samples greater than 200 CFU/100 mL, 235 CFU/100 mL, and 70 CFU/100 mL for fecal coliforms, *E. coli*, and *Enterococci*, respectively. Exact chi-square tests were calculated to compare the frequency of exceedance of each water quality criterion by CAFO sampling site and by B versus A site. Odds ratios (OR) and 95% confidence intervals (CI) were estimated using conditional fixed-effects logistic regression models to account for repeated sampling at each site (Allison, 2005).

To quantitatively compare concentrations of fecal indicator bacteria at A and B locations within Sites 1–3, the mean and 95% confidence interval were calculated for each fecal indicator's pair-wise difference of Site B minus Site A concentrations by site. A positive mean value indicates that the concentration of fecal indicator bacteria was higher at the Site B compared to Site A location. A negative mean value indicates the concentration of a fecal indicator was lower at the B site compared to the A site at each water sampling location.

The frequency of detection of candidate MST markers was tabulated across all sites and by site. Exact chi-square tests were calculated to compare the frequency of detection of candidate MST markers by site. Fixed effects linear and logistic regression models were used to estimate associations between fecal indicator bacteria, presence of swine markers, and rainfall (Allison, 2005). Cumulative rainfall during the 24 and 48 hours before sample collection was considered in analyses with fecal indicator bacteria and MST markers as a continuous (inches) and a binary (>versus ≤ the mean of cumulative inches of rainfall) variable.

Because this is not a randomized study, statistical significance cannot be interpreted as the probability that an observed difference would occur by chance if there is truly no difference between groups being compared. However, *p*-values are presented so that results can be easily compared with other studies. Fecal indicator bacteria concentrations were $\log_{10}$-transformed prior to analysis. All statistical analyses were performed using SAS version 9.2 (SAS Institute Inc., Cary, NC).

3. Results

3.1. Fecal indicator bacteria concentrations in surface waters proximal to swine CAFOs

The highest maximum concentrations of fecal coliforms, *E. coli*, and *Enterococci* observed were 140,000, 5400 and 10,400 CFU/100 mL, respectively, and were measured at Site B locations (Table 1). In general, the Site B samples had higher geometric mean and maximum fecal indicator bacteria values compared to Site A samples (Table 1). The highest concentrations of fecal indicator bacteria were detected in the spring and summer months (Fig. 2a-c).

3.2. Exceedance of recreational water quality guideline values proximal to swine CAFOs

For fecal coliforms, *E. coli*, and *Enterococcus*, 74/187 (40%), 43/187 (23%), and 112/185 (61%) of all surface water samples exceeded the respective recreational water quality guideline values of 200 CFU/100 mL, 235 CFU/100 mL, and 70 CFU/100 mL (Table 2). Across Sites 1–3, recreational water quality guideline value exceedance was 1.86 (95% confidence interval (CI) = 0.96, 3.62), 1.73 (95%

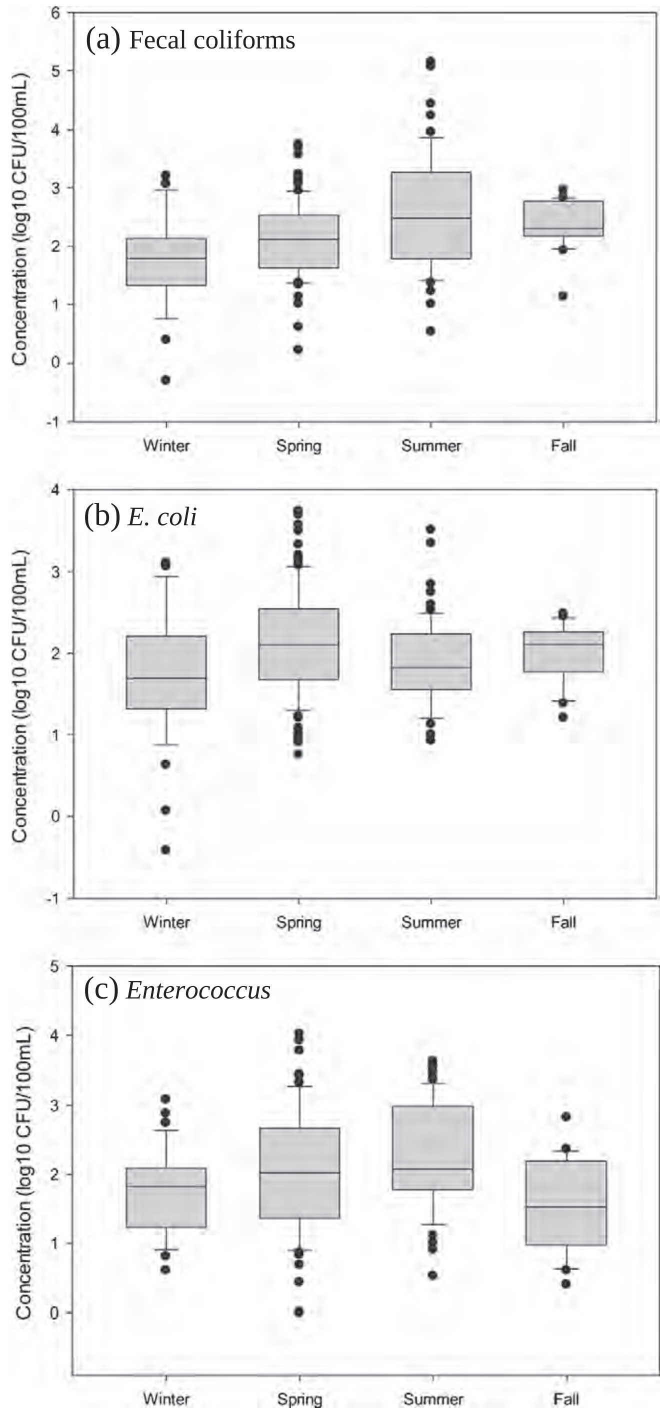

Fig. 2. a–c. Boxplot comparison of concentrations ($\log_{10}$ CFU/100 mL) of: (a) fecal coliforms (b) *E. coli* and (c) *Enterococcus* by season for all surface water samples at sites proximal to swine concentrated animal feeding operation spray fields in North Carolina. Median line and interquartile range depicted by boxes; range depicted by whiskers; outliers depicted by circular dots.

CI = 0.79, 3.78), and 1.49 (95% CI = 0.77, 2.88) times as prevalent at Site B compared to Site A locations (Table 2). For each of the fecal indicator bacteria, the greatest frequency of exceedance of recreational water quality guideline values was observed in the summer, followed by the spring (data not shown).

3.3. Mean pair-wise differences in fecal indicator concentrations

Across Sites 1–3, the means of the pair-wise differences (Site B value minus Site A value) for all three fecal indicator bacteria were positive (greater than the null value of mean equal to zero) (Table 3). The site-specific pair-wise differences were all positive except for *E. coli* at Site 3 and *Enterococcus* at Site 2 (Table 3). These two negative values were the smallest absolute differences in means observed.

3.4. Swine-specific fecal microbial source tracking markers in surface water proximal to swine CAFOs

The sensitivity of the three *Bacteroidales* markers Pig-1-Bac, Pig-2-Bac and Pig-Bac-2 was 80%, 87%, and 93%, respectively. The methanogen candidate swine-specific marker P23-2 was not detected in any of the known-source samples (while its internal amplification control was observed in every reaction). The specificities of Pig-1-Bac, Pig-2-Bac, and Pig-Bac-2 were 100%, 100%, and 37%, respectively.

The two *Bacteroidales* markers with 100% specificity for swine fecal pollution, Pig-1-Bac and Pig-2-Bac, were detected in 17% and 14% of surface water samples, respectively (Table 4). Pig-1-Bac was present each time Pig-2-Bac was detected and was also detected in six more samples than Pig-2-Bac. At sites where both A and B samples were collected (Sites 1–3), the difference in detection frequency at B compared to A sites was pronounced (Table 4). The odds of detecting the swine-specific fecal *Bacteroidales* marker Pig-1-Bac at Site B locations was 2.47 (95% CI = 1.03, 5.94) times the odds at Site A locations (Table 4). Site 1 demonstrated the most prominent difference in detection frequency between Site B and Site A (Pig-1-Bac OR = 6.76; 95% CI = 1.12, 40.8). The only instance in which the frequency of detection was higher at Site A than Site B was at Site 2 for *Bacteroidales* Pig-Bac-2. But Pig-Bac-2 was not a specific microbial source tracking marker for swine fecal waste. At Site 2, the two swine specific fecal *Bacteroidales* microbial source-tracking markers (Pig-1-Bac and Pig-2-Bac) were never detected at the Site A location. The swine-specific *Bacteroidales* markers Pig-1-Bac and Pig-2-Bac were most prominent during the winter (n = 32) months, with a detection frequency of 59% and 53%, respectively (data not shown). Pig-1-Bac and Pig-2-Bac were detected less frequently (15% and 10%, respectively) during the spring (n = 73) and were not detected during the summer (n = 62) and fall (n = 17) (data not shown).

3.5. Relation of rainfall with fecal indicator bacteria and swine-specific fecal microbial source tracking markers

In the 48 hours preceding sampling, the maximum cumulative inches of rainfall was 2.94 inches (Table S2). Mean fecal coliform, *E. coli* and *Enterococcus* levels increased as antecedent cumulative rainfall increased (Fig. 3; Table S3). Fecal coliforms, *E. coli*, and *Enterococcus* concentrations ($\log_{10}$ CFU/100 mL) increased 0.29 (95% confidence interval [CI] = 0.09, 0.49), 0.45 (95% CI = 0.27, 0.59), and 0.50 (95% CI = 0.31, 0.69), respectively, for every one-inch increase in cumulative rainfall in the 48 hours before sample collection, adjusting for season (Table S3).

Across all sites, the swine-specific fecal microbial source tracking markers Pig-1-Bac and Pig-2-Bac were detected more frequently when 48 hour antecedent cumulative rainfall (inches) was greater than versus less than or equal to the mean (Table 5). The odds of detecting Pig-1-Bac during time periods when 48 hour antecedent cumulative rainfall was greater than the mean were 2.87 times (95% CI = 1.21, 6.80) the odds during time periods when 48 hour antecedent cumulative rainfall was less than or equal to the mean (Table 5). Fecal indicator bacteria concentrations were not observed to be associated with swine-specific fecal microbial source tracking markers Pig-1-Bac and Pig-2-Bac (data not shown).

4. Discussion

The results of our study suggest an overall diffuse and poor microbial quality of surface waters proximal to swine CAFO liquid waste land application sites in NC, the second largest hog-producing state in the US. Fecal indicator bacteria were detected at concentrations that exceeded federal and state recreational water quality guideline values, with the highest concentrations observed immediately downstream of swine CAFO spray fields and in the spring and summer seasons. While some mean differences in fecal indicator bacteria were detected at Site A (proximal upstream) and Site B (proximal downstream) surface water sampling locations (e.g., higher Site B maximum values; positive mean pair-wise difference values; higher frequency of exceedance of fecal indicator guideline values at Site B compared to Site A locations), fecal indicator bacterial contamination was observed at both A and B locations.

While the study design allowed a comparison of Site A (upstream) and Site B (downstream) locations proximal to swine CAFO liquid waste land application sites, it is important to note that the Site A locations did not represent pristine non-impacted sites. Because the study sites in eastern NC were located among one of the top hog-dense counties in the US (Feedstuffs, 2013a,b; USDA, 2007), the Site A (proximal upstream) locations in our study were potentially influenced by numerous upstream swine CAFO liquid waste land application sites as well as poultry CAFO dry litter land application sites. Because fecal indicator bacteria (fecal coliforms, *E. coli*, *Enterococcus*) are non-specific indicators

Table 2
Frequency of exceedance of recreational water quality guideline values for fecal coliforms, *E. coli*, and *Enterococcus* at A and B sites proximal to swine concentrated animal feeding operation spray fields in North Carolina.

	Fecal coliforms		*E. coli*		*Enterococcus*	
	(200 CFU/100 mL)[a]		(235 CFU/100 mL)[b]		(70 CFU/100 mL)[b]	
	N exceed/total (%)	OR (95% CI)[c]	N exceed/total (%)	OR (95% CI)[c]	N exceed/total (%)	OR (95% CI)[c]
All sites	74/187 (40)	–	43/187 (23)	–	112/185 (61)	–
All A sites 1–3	24/76 (32)	Ref	13/76 (17)	Ref	40/75 (53)	Ref
All B sites 1–3	35/76 (46)	1.86 (0.96, 3.62)	20/76 (26)	1.73 (0.79, 3.78)	47/75 (63)	1.49 (0.77, 2.88)
All B sites 4–6	15/33 (46)	–	10/33 (30)	–	25/33 (76)	–

Note. Site A = proximal upstream sampling location. Site B = proximal downstream sampling location. OR = odds ratio. CI = confidence interval.
CFU = colony forming unit. Ref = referent category.
[a] Based on North Carolina Department of Environment and Natural Resources surface water standards (NCDENR, 2007).
[b] Based on 2012 USEPA recreational water quality criteria beach action values (BAV) (EPA, 2012).
[c] Odds ratio and 95% confidence interval derived from fixed-effects logistic regression model to account for repeated measures at each site.

Table 3
Mean of pair-wise differences of fecal indicator bacteria concentrations (CFU/100 mL) in surface waters at B sites minus A sites proximal to swine concentrated animal feeding operation spray fields in North Carolina.

	Fecal coliforms			*E. coli*			*Enterococcus*		
	CFU/100 mL			CFU/100 mL			CFU/100 mL		
	N[a]	Mean[b]	95% CI	N[a]	Mean[b]	95% CI	N[a]	Mean[b]	95% CI
All sites 1–3	75	2266	−1180, 5712	75	129	−49, 307	74	89	−103, 281
Site 1	13	384	−357, 1125	13	504	−347, 1355	13	341	−145, 827
Site 2	31	4387	−3886, 12,660	31	117	−83, 317	30	−32	−350, 286
Site 3	31	934	−228, 2096	31	−19	−156, 118	31	99	−177, 375

Note. Site A = proximal upstream sampling location. Site B = proximal downstream sampling location. CI = confidence interval.
[a] Number of pair-wise samples.
[b] Mean of the pair-wise differences of concentrations of each fecal indicator bacteria (B sites minus A sites).

of fecal pollution – reflecting inputs from diverse fecal waste inputs, including hog and poultry CAFOs as well as other diffuse sources – this could account for the elevated levels of fecal indicator bacteria at Site A (proximal upstream) compared to Site B (proximal downstream) locations.

Bacteriodales markers Pig-1-Bac and Pig-2-Bac, which were developed and validated in other regions of the world, were tested against known-source swine and other animal fecal samples from NC and both showed a specificity of 100% to known-source swine fecal wastes. This supports the findings of Mieszkin et al. (2009) who also observed specificities of 100% for both markers in France. The lower sensitivity of Pig-1-Bac (80%) and Pig-2-Bac (87%) than observed in France (98–100%) may be explained by our inclusion of swine wallow water as a potential source of swine waste, which was not investigated in the French study (Mieszkin et al., 2009). Exclusion of these swine wallow water samples (which tested negative) would have resulted in a higher sensitivity for Pig-1-Bac (92%) and Pig-2-Bac (100%).

This is the first study to examine whether Pig-1-Bac and Pig-2-Bac would be appropriate as indicators of swine-specific fecal waste run-off under field conditions at ambient surface water locations proximal to swine CAFO liquid waste land application sites in NC. The presence of swine-specific Pig-1-Bac and Pig-2-Bac fecal MST markers off-site in these surface waters indicates that swine CAFO liquid waste land application practices in NC can lead to off-site migration of swine fecal wastes. Our observation that Pig-1-Bac was 2.47 times as prevalent at proximal downstream compared to proximal upstream sampling locations also suggests that fecal wastes from swine CAFO liquid waste land application sites can negatively influence proximal downstream surface water quality.

During our study period, the maximum cumulative rainfall 48 hours antecedent to sampling was 2.94 inches (Table S2), which is not suggestive of heavy rainfall conditions. The low amount of rainfall during our study is relevant to the NC regulatory framework because it requires that animal waste management systems “not cause pollution in the waters of the State, except as may result because of rainfall from a storm event more severe than the 25-year, 24-hour storm” (NCGA, 1995). Neighbors and community groups in NC have observed swine CAFO operators spraying before forecasted rainfall and also during rain events to avoid an overflow or breach of waste lagoons.

Rainfall was strongly associated with fecal indicator bacteria concentrations in our study – particularly *E. coli* and *Enterococcus* – which is consistent with a loading mechanism of increasing fecal indicator bacteria levels in surface waters during rainfall-induced run-off. Future studies should employ a sampling strategy to capture the effects of rainfall through targeted sampling at multiple time points during storm events to characterize the temporal dynamics of fecal pollution loading during run-off conditions. Future studies should also target specific swine liquid waste spraying events — i.e., sampling at times during and after swine liquid lagoon wastes are sprayed onto fields.

Rainfall was strongly associated with the frequency of detection of Pig-1-Bac and Pig-2-Bac MST markers. Pig-1-Bac and Pig-2-Bac were detected roughly three times as frequently during periods when cumulative antecedent 48 hour rainfall was greater than versus less than or equal to mean rainfall. This association between rainfall and swine-specific MST markers Pig-1-Bac and Pig-2-Bac provides evidence of a rainfall-induced loading mechanism of swine fecal wastes in surface waters proximal to and off-site of swine CAFO liquid waste land application sites. However, the sample size was too small to draw conclusions about rainfall-swine MST marker associations at Site B (proximal downstream) compared to Site A (proximal upstream) locations.

Concentrations of fecal indicator bacteria and exceedances of recreational water quality guideline values were not associated with the presence of swine MST markers (data not shown). Because fecal indicator bacteria reflect both point and non-point sources of fecal pollution from warm-blooded animals as well as other non-fecal sources (e.g., bacterial re-growth in the environment (Byappanahalli et al., 2006)), it is not surprising that these measures were observed to be poor predictors of MST markers specific to swine fecal wastes.

Mieszkin et al. (2009) reported that Pig-2-Bac was a more suitable marker than Pig-1-Bac because it was detected more frequently in water samples. Our field assessment in NC slightly contradicts these findings because we detected Pig-1-Bac in six samples in which Pig-2-Bac was not detected, while Pig-2-Bac was never detected in the absence of Pig-1-Bac. Our results suggest that it may be advisable to utilize both markers together, as protocols involving two PCR assays from the same DNA extract do not involve much additional cost or effort compared to protocols involving one PCR assay.

Table 4
Occurrence of two swine-specific fecal *Bacteroidales* microbial source tracking markers in surface water samples at A and B sites proximal to swine concentrated animal feeding operation spray fields in North Carolina.

	Pig-1-Bac		Pig-2-Bac	
	N pos./total (%)	OR (95% CI)[a]	N pos./total (%)	OR (95% CI)[a]
All sites	31/182 (17)	–	25/182 (14)	–
All A sites 1–3	10/74 (14)	Ref	8/74 (11)	Ref
All B sites 1–3	20/75 (27)	2.47 (1.03, 5.94)	16/75 (21)	2.30 (0.90, 5.88)
All B sites 4–6	1/33 (3)	–	1/33 (1)	–

Note. Site A = proximal upstream sampling location. Site B = proximal downstream sampling location. OR = odds ratio. CI = confidence interval.
[a] Odds ratio and 95% confidence interval derived from fixed-effects logistic regression model to account for repeated measures at each site.

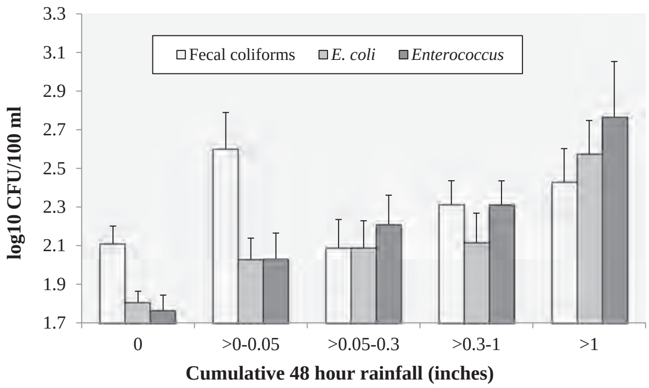

Fig. 3. Mean fecal indicator bacteria concentrations (log10 CFU/100 mL) by cumulative amount of rainfall (inches) during the 48 hours prior to sampling at sites proximal to swine concentrated animal feeding operation spray fields in North Carolina. Error bars represent the standard error of mean fecal indicator bacteria concentrations.

It is possible that swine fecal wastes were present in surface water samples when Pig-1-Bac and Pig-2-Bac were not detected. Sensitivity below 100% indicates that the MST marker was not detected in all known-source swine fecal waste samples. Furthermore, the persistence of these *Bacteriodales* MST markers (which are based upon anaerobic bacteria) is not well understood under ambient surface water conditions. A study of the effect of oxygen and temperature on the persistence of Pig-1-Bac and Pig-2-Bac reported a one-log reduction of the markers after eight to ten days in microcosms at 20 °C under aerobic conditions (Marti et al., 2011).

The seasonal variability of Pig-1-Bac and Pig-2-Bac in this study was somewhat surprising considering Mieszkin et al. (2009) reported temporal stability of Pig-1-Bac and Pig-2-Bac over a 48-month period. However, Mieszkin et al. (2009) likely meant that the markers were stable from year to year, as they did include enough samples to test seasonal differences. Recent research has established that lower temperatures result in slower *Bacteroidales* 16S rRNA gene decay (Bell et al., 2009; Schulz and Childers, 2011). Because Pig-1-Bac and Pig-2-Bac may persist in colder environments and decay more rapidly in warmer environments, it is possible that they were either absent in the environmental samples collected in NC during the warmer months, or were present at levels below the assay detection threshold. The warmer temperatures in NC could explain why these markers were not detected throughout the year.

This seasonal pattern, where the swine-specific MST markers were detected more frequently in winter, is in direct contrast to the typical seasonal pattern observed for fecal indicator bacteria. In this study and elsewhere (Cha et al., 2010; Tiefenthaler et al., 2009; Wilson et al., 2007), measures of fecal indicator bacteria in water are typically higher in warmer (summer) than in colder (winter) months. This marked difference in seasonal patterns is most likely attributable to the fact that traditional measures of fecal indicator bacteria are culture-based and target vegetative bacterial cells accustomed to growing in the warm environment of mammalian guts. Microbial source tracking markers, on the other hand, typically rely on detection of DNA specific to the cells of anaerobic bacteria. Both the cells and the DNA degrade more quickly in warm weather, likely causing lower frequencies of their detection in summer months (Schulz and Childers, 2011). Rainfall, which was higher during the spring and summer months of our study, may also contribute to the observed seasonal pattern of Pig-1-Bac and Pig-2-Bac presence.

The low specificity of Pig-Bac-2 (37%) demonstrates that this marker was not useful to distinguish swine from other animal sources of fecal waste. This marker had a low specificity because it was detected in chicken, cow, goat, horse, human, and turkey fecal samples. To our knowledge no other study has investigated the sensitivity and specificity of Pig-Bac-2 since publication of the assay, which included test samples from humans, cows and swine (Okabe et al., 2007). Lamendella et al. (2009) also observed a poor specificity of Pig-Bac-1, the other swine *Bacteroidales* marker proposed by Okabe et al. (2007), because it was detected in cattle, human, chicken, raccoon, and horse fecal samples. Since we did not detect Methanogen P23-2 in any known source sample (swine or other animal) or in any surface water samples, it appears to have limited utility for detecting swine waste in surface water samples in NC.

Several study limitations should be considered. We did not sample known-source swine fecal wastes from the lagoons of the swine CAFOs proximal to our selected surface water sampling sites. Future studies could improve understanding of off-site transport through on-site sampling of swine CAFOs spray-field run-off and of lagoon waste in addition to the proximal surface waters. We did not generate quantitative PCR results for Pig-1-Bac and Pig-2-Bac. Although assays were run on a real-time PCR machine, materials for a standard curve were not available and cycle threshold values were not recorded, which restricted analysis of these markers to their presence versus absence. Due to the high density of swine and other animal CAFOs in the study area we were unable to sample at un-impacted or pristine upstream sites. Future studies should attempt to include such un-impacted sites and also consider use of additional microbial source tracking markers to evaluate the relative contribution of swine versus other animal sources (e.g., chicken, turkey, human) of fecal pollution.

5. Conclusions

Evidence of high concentrations of fecal indicator bacteria and the presence of swine-specific fecal MST markers in surface waters proximal to swine CAFO liquid waste land application sites is relevant to evaluating the effectiveness of current technologies and policies for protecting the sanitary quality of surface waters proximal to swine CAFOs. These results could inform management decisions about liquid waste disposal practices, particularly landscapes where swine density is high and that are susceptible to over-land run-off from rainfall and flooding (e.g., NC coastal plain) (Wing et al., 2002). Use of swine-specific fecal MST markers Pig-1-Bac and Pig-2-Bac could help identify surface waters for targeted restoration, and help inform rules governing permitting, waste management (including storage,

Table 5
Relation between occurrence of swine-specific fecal *Bacteroidales* microbial source tracking markers in surface water samples and cumulative rainfall in the 48 hours before sample collection at sites proximal to swine concentrated animal feeding operation spray fields in North Carolina.

	Pig-1-Bac		Pig-2-Bac	
	N pos./total (%)	OR (95% CI)[a]	N pos./total (%)	OR (95% CI)[a]
All sites				
Cum. rainfall ≤ mean[b]	16/131 (12)	Ref	12/131 (9)	Ref
Cum. rainfall > mean[b]	15/53 (28)	2.87 (1.21, 6.80)	13/53 (25)	3.36 (1.34, 8.41)

Note. OR = odds ratio. CI = confidence interval.
[a] Odds ratio and 95% confidence interval derived from fixed-effects logistic regression model to account for repeated measures at each site.
[b] Stratified by time periods > vs ≤ the mean cumulative inches (0.248) of rainfall in the 48 hours before sample collection.

treatment, and disposal), and swine stocking density. Future studies should utilize swine-specific *Bacteroidales* fecal MST markers as they appear to represent important tools to advance understanding of impacts on water quality in areas with intensive swine production.

Abbreviations

CAFO concentrated animal feeding operation
CFU colony forming unit
PCR polymerase chain reaction

Author contributions

The manuscript was written through contributions of all authors. All authors have given approval of the final version of the manuscript.

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Appendix A. Supplementary data

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Exhibit 13 to the
Declaration of Professor Steven B. Wing, Ph.D.

Environmental Injustice and the Mississippi Hog Industry

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The recent growth and restructuring of the swine industry in the state of Mississippi has raised various environmental and socioeconomic concerns. We spatially examined the location and attributes of 67 industrial hog operations to determine if African American and low-income communities have a high prevalence of industrial hog operations located near their neighborhoods at the census block group level. We used spatial data and cross-classification analysis to compare the prevalence of industrial hog operations in neighborhoods that are primarily African American and low income with the prevalence in neighborhoods that are African American and affluent. We also used logistic regression to evaluate the relationship between the environmental justice variables and the location of the industrial hog operations. The block group characterization showed a high prevalence of hog operations in the four highest quintiles compared with the lowest quintile for percentage African American and percentage poverty. At increasing levels of percentage African Americans and percentage of persons in poverty, there are 2.4–3.6 times more operations compared with the referent group; additionally, scale adjustment to only the hog counties reduces this to 1.8–3.1 more operations compared with the referent group. The inequitable distribution of hog-confined agricultural feeding operations in these communities may have adverse environmental impacts associated with industrial hog production, such as increased health risks and quality of life degradation, as have occurred in other areas having similar facilities. ***Key words*****: African Americans, CAFOs, census blocks, confined agricultural feeding operations, disproportionate, environmental health, environmental justice, geographic information systems, hog industry, poor, rural.** ***Environ Health Perspect*** **110(suppl 2):195–201 (2002).**
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Because of the application of vertical integration management practices, hog farming has in some locales been transformed into a high-density industrial production system. Production of large numbers of hogs in small confined areas produces a multitude of environmental impacts (e.g., air and water pollution) that potentially can have adverse outcomes for rural non-White and poor populations. Specifically, non-White and poor communities with limited political and economic resources to mitigate the problem may be disparately burdened. In this study we used environmental and census data to examine environmental justice issues associated with industrial swine production in Mississippi.

Mississippi, one of the poorest states in the United States, has used its ample land resources to draw economic development to the region (*1*). One of its prominent suitors has been the swine industry. Although the state's physical characteristics may play a role (*1*), there are other important reasons for the industrialization of hog production in the state. First, there was a rapid decline in large-scale packers in the South, with Bryan Foods as the only such packer in the region that employs more than 1,000 persons (*2*). Bryan Foods increased its packing capacity and developed a relationship with Prestage Farms, which would supply hogs to Bryan Foods (*2*). Second, in 1993, the state amended Section 69-2-19, Mississippi Code of 1972 to increase the maximum amount of bonds that the Mississippi Department of Economic and Community Development could issue under the auspices of the Emerging Crops Fund (*3*). This amendment and later amendments in 1995, 1996, and 1998 helped provide the state of Mississippi with a bonded finance program for a broad range of agricultural production under the emerging crops fund, including Christmas trees, rabbit farming, poultry, and hogs (*3*). The fund was originally focused on helping both crop and animal farmers become more competitive. However, it has evolved into a mechanism that pork producers use to establish new large-scale operations (*4*). The reasons described above are not directly related to either poverty or race but within the 50- to 75-mile buffer around the large packing plant in West Point, Mississippi, race and poverty become important criteria for site selection (*2*).

Agricultural economists in the state estimated that its 1998 pork production had a 24% decline in value from the previous year (*5*). As result, many of Mississippi's independent producers have recently gone out of business or are at risk of losing their family-run operations (*5*). This economic loss has given out-of-state hog corporations the incentive to bring industrial swine production to Mississippi. For example, earlier in the 1990s, the state mainly had smaller farms with several hundred hogs and only one or two industrial swine operations with over 1,000 animal units (AUs) that could be categorized as confined agricultural feeding operations (CAFOs) (*6*). The influx of large corporations has changed the entire landscape of hog farming in the state. The number of industrial hog facilities has risen from 0 to 60 in just the past 10 years, and production has increased despite the decline in the number of hog farms (*4*).

Some citizens of the state feel that corporate swine operators are adversely affecting their health and the vitality of their communities (*1*). Research has shown that industrial pork production may cause environmental health problems for ecosystems and humans (*7–9*). The new trend of large-scale production involves a high density of hogs grown in confinement houses and producing vast amounts of waste. The hog waste is collected and stored through different systems, including below-floor slurry storage (deep pit), underground slurry storage, anaerobic lagoons, and oxidation pits (*10*). One of the most popular methods is the storage of the waste in anaerobic cesspools, commonly called "lagoons," where it undergoes microbial digestion. The hog waste effluent is later sprayed onto fields.

This system of pork production and waste management introduces several problems. Noxious gases are released through a ventilation system from the confinement houses (*11*), and environmental contaminants are also released via volatilization from the waste decomposing in lagoons, sprayfields, and other waste collection sites. Some of the environmental contaminants emitted

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into the atmosphere include ammonia, hydrogen sulfide, volatile organic compounds, particulates, and other pollutants (*12–14*). The contaminants can cause health problems for individuals exposed occupationally in the confinement houses (*12–14*). In addition, community members who live close to the operations may have adverse health effects such as irritation to their eyes, noses, and throats (*8,9,15*); decline in quality of life (*9*); and possible mental health disorders (*15,16*). There are also water quality problems associated with leakage from the lagoons (*17–19*) and runoff from the sprayfields (*7*) that can contaminate surface and groundwater.

The concentration of the pollution-intensive swine industry in the northeastern portion of the state becomes an important environmental justice problem. Mississippi has a large population of rural citizens who are non-White and poor, which may make their communities more susceptible to health risks associated with residing near large numbers of hog facilities (*20*). The contaminants released from industrial hog operations pose a significant threat to public health, environmental quality, sustainable economic development, and community stability and vitality. Similar issues have been raised in other hog-producing states such as Iowa and North Carolina. For example, research studies in North Carolina have provided evidence at the county and block group level of environmental inequities in the distribution of industrial hog operations (*21–24*). The evidence also indicates that adverse social and environmental impacts of swine waste follow a course of less political resistance (*24*). In essence, industrial hog operations have located in non-White and low-income communities in eastern North Carolina, the state's poorest and most politically marginalized region (*24*).

Both Iowa and North Carolina have well-developed CAFO-based hog production systems. We do not yet know how issues of environmental equity fare in states where concentrated swine operations are present but less well developed than in Iowa or North Carolina. Moreover, the racial diversity of a state's population base may well affect the pattern of environmental equity observed. For instance, in Iowa, the African American population is very small as a percentage of the total population base, whereas African Americans heavily populate North Carolina's eastern territory. Mississippi has many counties with a significant to substantial percentage of the population identifying themselves as African American but where CAFO-style swine production has only recently emerged. Thus, the use of Mississippi as a study site facilitates the investigation of environmental equity issues during the initial development phase of CAFO-style swine production. Using Geographic Information Systems (GIS) and sociodemographic data for census block groups, we examined the association between the location of industrial swine operations and their proximity to non-White (e.g., African American) and poor communities.

Materials and Methods

CAFO Definition and NPDES Data

We obtained a 1997 list of the National Pollution Discharge Elimination System (NPDES)-permitted swine operations in Mississippi from the Department of Environmental Quality (DEQ). NPDES regulates the discharge of pollutants from point sources to waters of the United States (*25–27*). The U.S. Environmental Protection Agency (U.S. EPA) Clean Water Act identifies CAFOs as point sources that are required to secure NPDES permits (*26,27*). The U.S. EPA defines a CAFO as an animal feeding operation (AFO) with more than 1,000 AUs confined at the facility. In addition, a CAFO can be an AFO with 301–1,000 AUs confined at the facility if *a*) pollutants are discharged directly into the waters of the United States through a man-made system or *b*) waters that originate off-site of the facility pass over, across, or through the facility or come in direct contact with the confined animals (*26,27*). The 1997 list obtained from the Mississippi DEQ included descriptive information on 69 hog operations classified as CAFOs. The information includes facility name, permit number, contact person, city/county location, number of animals, and latitude/longitude coordinates.

Geographic Information System Application

We used the GIS program to check and correct the latitude/longitude coordinates in the database (*2*). A list of corrected latitude/longitude coordinates covered 67 operations permitted or in the permitting process as of 1997. The hog operation coverage was generated in Arcview 3.1 (*28*) and included information on 67 of the 69 hog CAFOs. The two excluded facilities had incomplete information and therefore were not used in the analysis. We used the GIS program to attach information from the database to the hog coverage shapefile, a file that visually displays the geographic coordinates of the hog CAFOs.

Census Data and Environmental Justice Variables

We obtained data on race and poverty from the 1990 Census Summary Tape file (STF 3A) (*29*). Growth of corporate hog production was just beginning around 1990, so census data for that period represent the characteristics of the populations of the areas chosen for expansion. Block groups are the smallest census aggregation that includes race/ethnicity and socioeconomic status (*30*). Census block groups contain, on average, approximately 1,000 persons or 500 households.

We defined poverty according to the federally established poverty threshold in 1990. This threshold is based on the definition originated by the Social Security Administration in 1964 and approved by the Office of Management and Budget in Statistical Policy Directive 14 (*31*). Population size and density of the census block groups were also obtained.

Analytic Methods

In Mississippi, as in most agricultural states, most livestock are raised in rural locations. There are no intensive livestock operations located in metropolitan areas such as the Biloxi–Gulfport area or the Jackson, Mississippi, metropolitan area. There is also an absence of large hog operations in small towns not in the northeast section of the state or in the Delta, the large geographic area on the western side of the state adjacent to the Mississippi River.

We organized our geographic analyses into two phases. In the first geographic analysis we examine the distribution of African Americans and persons in poverty in relation to the location of hog CAFOs in the entire State of Mississippi, which consists of 2,392 census block groups. In the second geographic analysis, we excluded most of the densely populated areas and municipal census blocks because they could distort the relationship between the hog operations and the environmental justice variables. The hog counties analysis contained the census block groups located in counties that had at least one industrial hog operation. Sixteen counties (containing 352 block groups) had at least one hog CAFO.

We first investigated the relationship between each environmental justice variable and the presence of hog CAFOs by dividing block groups into quintiles of each environmental justice variable and calculating the number of hog operations in the different levels of the study variables (*22*). The ratio of the number of hog CAFOs in each higher quintile compared with the lowest quintile is defined as the prevalence ratio. We mapped hog CAFOs and the environmental justice variables to exhibit their spatial relationships. In addition, the variables of percentage of poverty and percentage of African Americans were cross-classified in two-way tables. Because quintiles cannot be defined simultaneously for

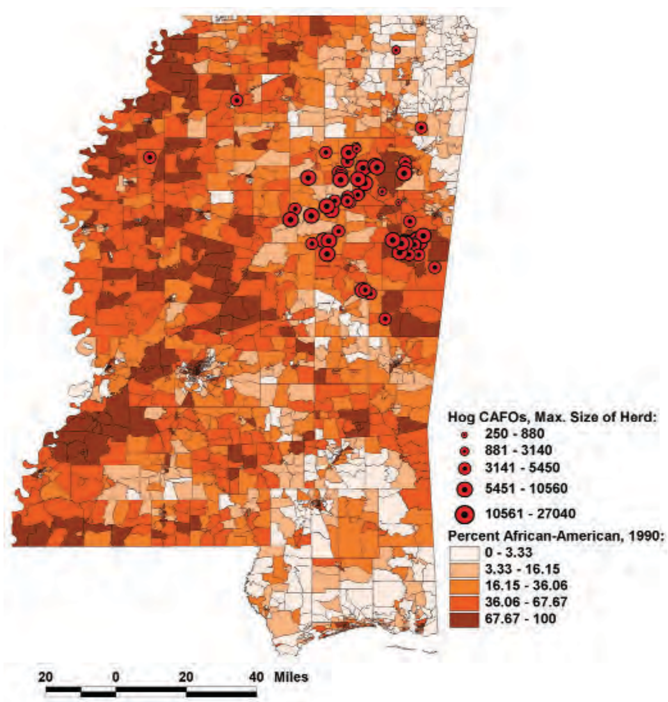

Figure 1. Hog CAFOs in proximity to percentage of African American, State of Mississippi, 1990.

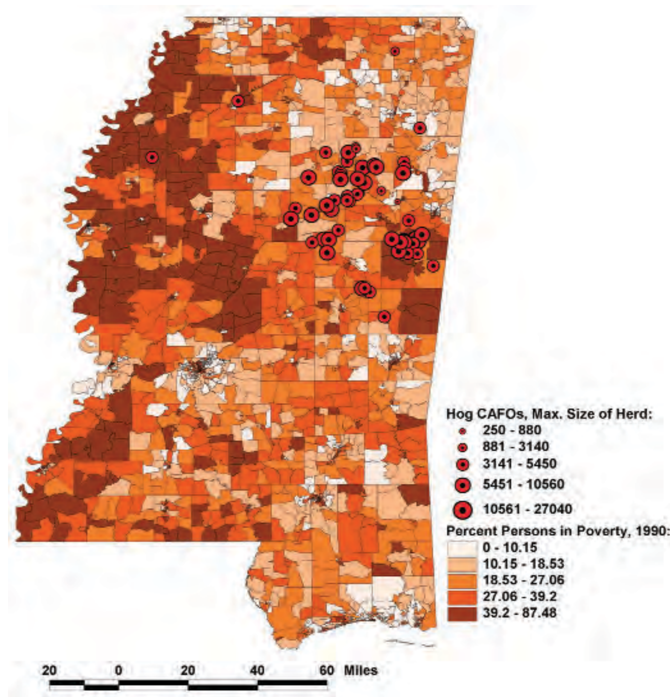

Figure 2. Hog CAFOs in proximity to percentage of poverty, State of Mississippi, 1990.

both variables, and univariate relationships were not linear, we chose boundaries for the cross-classification that corresponded to higher and lower ranges of prevalence: above or below 29% for African American and above or below 25% for poverty.

We used logistic regression to estimate odds ratios and their 95% confidence limits for the impacts of race and poverty on presence of CAFOs with adjustment for population density. A similar approach was used previously in a study of CAFO locations in North Carolina (*22*). Population density was included as a covariate to evaluate whether associations with environmental justice variables could be explained statistically by a measure of rurality. For block groups in the hog counties, we examined the presence or absence of one or more CAFOs (the dependent variable) in relation to race, poverty, the natural log of population density, and the interaction of race and poverty. Environmental justice variables were coded as in the cross-classification analyses described above. We used Statistical Analysis System (*32*) software to estimate parameters and their variances and covariances.

Table 1. Characteristics of block groups in relation to race in the State of Mississippi analysis.

Environmental justice variable	Quintiles	Total population	No. of hogs	No. of block groups	No. of CAFOs	Population density (per square mile)
Percentage of African American	0–3.33	461,960	0	478	0	1,892
	3.33–16.15	540,649	14,020	479	3	1,005
	16.15–36.06	534,042	118,900	478	25	925
	36.06–67.67	495,525	114,559	478	26	3,605
	67.67–100	541,040	94,240	479	13	2,421

Table 2. Characteristics of block groups in relation to poverty in the State of Mississippi analysis.

Environmental justice variable	Quintiles	Total population	No. of hogs	No. of block groups	No. of CAFOs	Population density (per square mile)
Percentage of persons in poverty	0–10.17	514,289	250	478	1	5,013
	10.17–18.56	531,202	50,260	479	11	854
	18.56–27.06	506,357	111,829	477	24	660
	27.06–39.2	503,544	92,640	478	19	996
	39.2–87.48	515,724	86,740	478	12	2,019

Results

State of Mississippi Analysis—Chloropleth Maps

Figure 1 is a chloropleth map displaying the spatial location of the hog CAFOs in relation to quintiles of percentage of African American for the entire State of Mississippi. This figure shows the locations of the 67 swine operations in the entire state using red dots; each dot represents an active swine operation. The size of the dots signifies the size of each individual hog operation (see legend). The map shows that corporate pork production occurs mainly in a dense corridor in the northeastern section of the state. In addition, we see that approximately 35% of the state's population is African American. There are high numbers of African Americans distributed across major geographic expanses of the state, especially in the central region and western portion of the state that borders the Mississippi River. The area that borders the river is known as the Mississippi Delta, a fertile agricultural region in the western part of the state whose African American citizens are primarily the descendants of slaves and sharecroppers. However, in the northeastern extreme of the state and census block groups close to the Mississippi Gulf Coast, we see census units with low numbers of African Americans.

Figure 2 shows the distribution of poverty in the state. Approximately 25% of the persons in the state live below the poverty level (*31*). Some low-poverty areas and many high-poverty areas are located near the hog CAFOs. Most of the high-poverty areas are in census block groups in the Mississippi

Delta, central–west Mississippi, and Jackson, the capital of the state.

State of Mississippi Analysis—Prevalence Data

Tables 1 and 2 display the attributes of block groups in relation to percentage of African Americans and percentage of persons in poverty. Block groups in the lowest quintile of percentage of African Americans have no hog operations. In addition, only three hog operations are located in the second quintile of percentage of African Americans. In contrast, the highest three quintiles of percentage of African Americans have 64 of the 67 industrial swine operations.

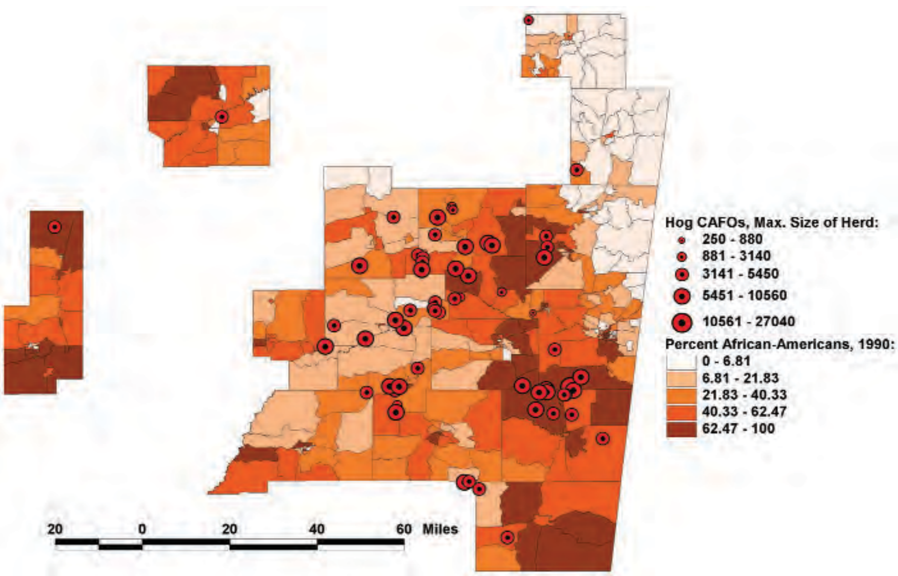

Figure 3. Hog CAFOs in proximity to percentage of African Americans, Mississippi hog counties, 1990.

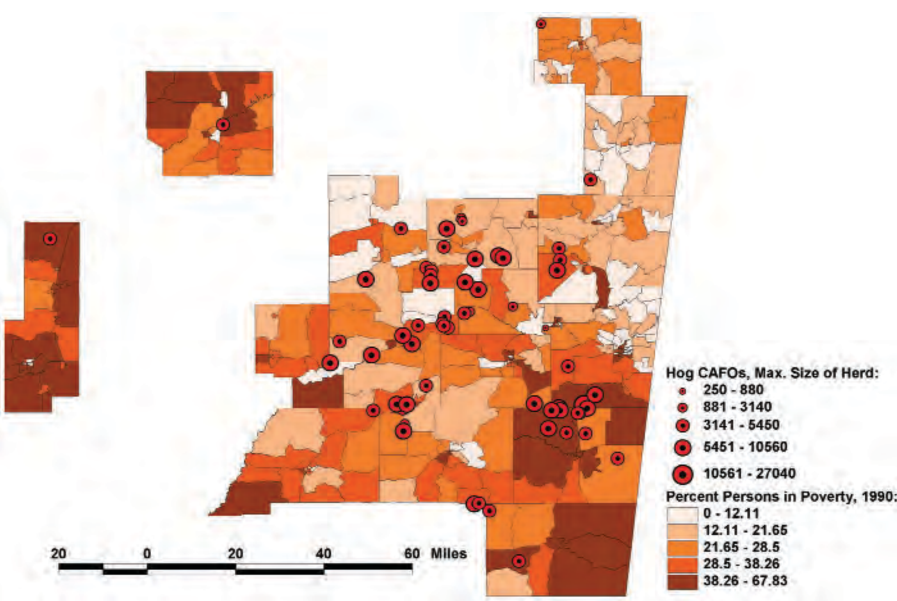

Figure 4. Hog CAFOs in proximity to percentage of poverty, Mississippi hog counties, 1990.

Table 3. Characteristics of block groups in relation to race in the Mississippi hog counties analysis.

Environmental justice variable	Quintiles	Total population	No. of hogs	No. of block groups	No. of CAFOs	Population density (per square mile)
Percentage of African Americans	0–6.81	61,501	3,140	70	1	458
	6.81–21.83	84,351	52,000	70	9	550
	21.83–40.33	70,976	78,030	71	19	487
	40.33–62.47	76,482	102,299	70	23	322
	62.47–100	93,781	106,250	71	15	920

Table 2 presents information on the characteristics of the block groups for the percentage of people in poverty variable for the state of Mississippi. In the lowest quintile of the variable, only one industrial hog operation and 11 hog CAFOs are located in the second-lowest quintile. In contrast, 55 hog CAFOs are in the highest three quintiles for the percentage of persons in poverty variable. The largest number of CAFOs occurs in the third quintile.

Mississippi Hog Counties Analysis—Chloropleth Maps

We created a second series of maps to examine the association between the study variables and the distribution of hog CAFOs in counties that had at least one operation. These chloropleth maps do not contain the block groups of metropolitan areas or non–hog CAFO counties. Figure 3 shows the geographic distribution of percentage African American populations for 352 block groups. The figure reveals that most of the block groups in this analysis have large populations of African Americans. The census block groups in the area with lower numbers of African Americans are located in the far northeastern portion of the study area near the Alabama border and in the central region of the map. Many of the hog CAFOs are located in block groups with greater than 22% African American population. Figure 4 shows the spatial distribution of poverty in the 352-block group study area. There are low numbers of persons living in poverty in census block groups in the northeastern portion of the study area and interspersed in the central region of the map. Some of the industrial hog operations are distributed in low-poverty areas. Figure 4 shows that the majority of the hog CAFOs are in areas with greater than 22% persons in poverty.

Mississippi Hog Counties Analysis—Prevalence Data

Table 3 shows the distribution of hog CAFOs in relation to the proportion of African Americans in the hog counties. In the lowest quintile for percentage of African Americans, there is only 1 hog operation. We find 9 industrial hog operations in the second quintile. In contrast, there are 57 industrial hog operations in the three highest quintiles of percentage of African Americans. In addition, the population densities are lower in the hog counties analysis, compared with the State of Mississippi geographic analysis. This is because of our exclusion of the urban and municipal block groups in the hog counties analysis. Block groups in the hog counties analysis are predominately rural and sparsely populated (Table 3).

Table 4 presents information on the characteristics of census block groups for the percentage of persons in poverty variable. There are 4 hog CAFOs in the lowest quintile of percentage of people in poverty and 13 in the second lowest quintile of the same variable. This compares with 50 hog CAFOs in the highest three quintiles of percentage of people in poverty (21.65–67.83% persons in poverty).

Prevalence Ratios

Table 5 shows the prevalence ratios for hog CAFOs cross-classified for combinations of the two environmental justice variables for the state of Mississippi geographic analysis. The table gives the prevalence (number of CAFOs per block group) for the cross-classified variables and the ratio of the prevalence of CAFOs at each level compared with the referent level. Together, block groups in the 0–25% poverty and 0–29% African American are the referent group. There are 3.64 times more hog operations in the high African American, low-poverty group compared with the referent group. There are 2.4 times more operations in the high African American, high poverty block groups compared with the referent group.

Table 6 provides prevalence ratios for the environmental justice variables in the Mississippi hog counties analysis. For this smaller area of study, a general decrease from the large values is seen in the prevalence ratios of the whole-state analysis. Block groups with 0–25% poverty and 0–29% African American are the referent group. The low-poverty and high African American block groups and the high-poverty, low African American block groups have prevalence ratios of approximately 3. At high percentages poverty and high percentages African American, the prevalence ratio is 1.79.

Table 7 shows results of a logistic regression model including race and poverty as indicator variables, their interaction, and the natural log of population density. Low African American, low-poverty areas are considered the referent group. Following adjustment for population density, there were 2.84 times as many CAFOs in high African American, low-poverty block groups compared with the referent, and 2.68 times as many in high-poverty, low African American block groups. The excess in high African American, high-poverty groups is 1.35 times; 95% confidence limits are fairly wide for these estimates, partly because there were only 36 block groups with one or more CAFOs.

Table 4. Characteristics of block groups in relation to poverty in the Mississippi hog counties analysis.

Environmental justice variable	Quintiles	Total population	No. of hogs	No. of block groups	No. of CAFOs	Population density (per square mile)
Percentage of persons in poverty	0–12.11	67,724	19,610	70	4	682
	12.11–21.65	73,969	56,340	71	13	335
	21.65–28.57	74,530	86,389	70	19	214
	28.57–38.26	72,734	89,120	71	18	537
	38.26–67.83	98,134	90,260	70	13	966

Table 5. Prevalence ratios of the numbers of hog CAFOs per block group for block groups classified by percentage of African American and percentage of poverty, state of Mississippi.

	Percentage of African American: 0–29				Percentage of African American: 29–100			
Percent poverty	Number of block groups	Hog CAFOs	Prevalence	Prevalence ratio	Number of block groups	Hog CAFOs	Prevalence	Prevalence ratio
0–25	1,066	15	0.014	1.00	254	13	0.051	3.64
25–100	210	10	0.048	3.38	860	29	0.034	2.40

Table 6. Prevalence ratios of the numbers of hog CAFOs per block group for block groups classified by percentage of African American and percentage of poverty, Mississippi hog counties.

	Percentage of African American: 0–29				Percentage of African American: 29–100			
Percent poverty	Number of block groups	Hog CAFOs	Prevalence	Prevalence ratio	Number of block groups	Hog CAFOs	Prevalence	Prevalence ratio
0–25	136	15	0.110	1.00	38	13	0.342	3.10
25–100	31	10	0.323	2.94	147	29	0.197	1.79

Table 7. Odds ratios and 95% confidence limits from logistic regression, Mississippi hog counties, 1990.

	0–25% Persons in poverty	25–100% Persons in poverty
0–29% African American	1.0 (referent group)	2.68 (0.75–9.56)
29–100% African American	2.84 (0.98–8.22)	1.35 (0.54–3.39)

Discussion

We examined the locations of 67 industrial hog operations in relation to race and poverty in neighboring census block groups in Mississippi. We found that the majority of the Mississippi's industrial hog operations are located in areas with high percentages of African Americans and persons in poverty. This evidence supports the idea that industrial pollution sources are disproportionately located in proximity to non-White and low-income communities (*23,24,33–40*). The study found distributional inequities in the location of hog CAFOs in non-White (African American) and poor communities. The environmental contamination from hog CAFOs can expose the burdened populations to harmful pollutants. The disproportionate number of industrial swine operations in these areas raises concerns about public health and quality of life (*8,9,41*) and may lead to economic decline in the affected communities (*8,24,35,42,43*).

The joint effects of race and poverty are also of interest. In the Mississippi hog counties and adjusting for population density, there are approximately 3 times as many CAFOs in high African American, low-poverty block groups compared with the referent, and also 3 times as many in high-poverty, low African American block groups compared with the referent. However, in high levels of both poverty and African American block groups, there are only 1.79 times as many hog CAFOs (Table 7). In areas that have high percentages of African Americans and persons in poverty, there may be a lack of political and economic infrastructure present to attract any new industries, even hog CAFOs.

Research has shown that living near industrial hog operations is a major public health concern for disproportionately burdened communities. Studies indicate that emissions from swine confinement houses are associated with adverse respiratory problems (*8,12,13,15*) and a decline in quality of life for communities in proximity to the hog CAFOs (*9,41*). Other data reveal that people who lived near livestock operations such as a hog CAFO reported irritating odors that caused negative respiratory effects and impaired mood disorders (*15,16*). Results analogous to those mentioned above were found in a study of the physical and mental health of residents who lived near a large-scale operation in Iowa (*8*).

Furthermore, the high density of swine CAFOs in rural census block groups can release environmental pollutants that degrade the water quality of these communities (*44*) and potentially increase the number of pathogenic microbial contaminants in surface and groundwater near swine lagoons and sprayfields (*7*). Lobao states (*42*) that an

> agricultural structure that was increasingly corporate and non–family owned tended to lead to population decline, lower incomes, fewer community services, less participation in democratic processes, less retail trade, environmental pollution, more unemployment, and an emerging rigid class structure.

Moreover, other findings have shown that large farms adversely impact the economic health of rural communities (*23*,*24*,*42*,*43*,*45*). This leads to community concerns about reduction in quality of life (*9*), depression of land and property values (*45*), farm loss (*23*), and interference with the growth of environmentally sustainable industries (*40,45*). All these impacts can destroy the interconnectivity of the personal, environmental, economic, and social health (*8*) of rural communities that are disproportionately exposed to industrial hog facilities.

Even though this study does not attempt to ascertain the causes of the social and racial inequities in the distribution of the intensive swine operations, there are credible reasons for this particular siting pattern in the state. Corporate hog operations in many agricultural states like Mississippi tend to locate facilities on the basis of economic factors such as the sociopolitical structure of the host communities and contiguity to other related operations, slaughterhouses, transportation routes, and infrastructure (*22*,*46*). Various economic, political, and institutional factors are important in the siting of hog CAFOs. For example, a major integrator opened a large hog-feed mill in West Point, Mississippi, with the intention of supplying feed to its own nearby feedlots in northeastern Mississippi. It also planned to establish facilities in the area to supply local hogs to a major food production company (*4*,*47*). The corporate integrator intends to establish dozens of hog farms within a 50- to 75-mile radius of its feed mill to supply one of the largest slaughterhouses in the South, also in the West Point area (*1*,*2*,*48*). The above information provides evidence of some reasons for the restructuring of the industry in the state.

Other important factors to consider when examining the spatial distribution of industrial swine operations in rural communities are low land prices, lack of community-based organizations advocating for environmental protection and public health, absence of CAFO zoning regulations and county legislation, economic incentive packages, and lack of other opportunities for local farmers. Economic development and environmental policies tend to result from the driving forces of production, (i.e., vertical integration) (*49*) and are often dominated and subsidized by state regulatory and commerce agencies (*22*). For instance, Mississippi state and county agencies offered millions of dollars in tax breaks and incentives to corporate integrators and paid for road improvements (*4*).

The aforementioned economic factors have contributed to the growth and restructuring of the swine industry in Mississippi. This pattern is similar to the growth and vertical integration of the industry in other states such as North Carolina, Minnesota, Utah, and Iowa. Unlike these other states, Mississippi does not have a large number of industrial hog operations. A 1998 moratorium and county zoning laws have combined to retard the growth of the industry (*1*,*50*). Future studies of environmental justice in the Mississippi swine industry should be conducted with more accurate data on the characteristics of the industrial hog operations to elucidate the nature of the geographic inequities. Information from the Mississippi DEQ database was not clear on type of operation, whether it was an independent operation or a corporate integrator (*51*). The calculation of prevalence ratios on the basis of operation type would show whether small independent farms or corporate integrators were more prevalent in non-White and poor communities than in affluent and White communities (*22*). In addition, a temporal analysis that includes operations that have pending permits can examine the potential future of the industry and ascertain whether the hog CAFOs are going to be located in areas where geographic inequities exist.

Conclusions

The inequitable distribution of swine operations is a threat to Mississippians because exposure to noxious odors, airborne contaminants, and microbial pollutants from the confinement houses, lagoons, and sprayfields is a concern for individuals with preexisting respiratory problems, children, elderly, and the uninsured. A new collective awareness has occurred in rural Mississippi (*51*). Citizens are concerned about the public health impact and ecologic risks introduced by intensive pork production. A number of non-White and poor communities have disproportionate numbers of hog CAFOs in their communities, which constitutes an environmental equity issue. The state could focus on attracting environment-friendly industries that could add to the economic stability and vitality of low-income and African American communities that currently have a disproportionate number of operations.

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