Advances and Current Themes in Occupational Health and Environmental Public Health Surveillance

Jeffrey D. Shire,[1] Gary M. Marsh,[2] Evelyn O. Talbott,[3] and Ravi K. Sharma[4]

[1]Department of Epidemiology, [2]Department of Biostatistics, Center for Occupational Biostatistics and Epidemiology, [3]Departments of Epidemiology, Graduate School of Public Health, and Communication Science and Disorders, School of Health Related Professions, [4]Institute for Evaluation Science in Community Health, Department of Behavioral and Community Health Sciences, Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pennsylvania 15261; email: jds82@pitt.edu, gmarsh@pitt.edu, eot1@pitt.edu, rks1946@pitt.edu

Annu. Rev. Public Health 2011. 32:109–32

First published online as a Review in Advance on January 3, 2011

The *Annual Review of Public Health* is online at publhealth.annualreviews.org

This article's doi:
10.1146/annurev-publhealth-082310-152811

0163-7525/11/0421-0109$20.00

Keywords

preventive medicine, legislation, workers, resource allocation, population surveillance

Abstract

The essential purpose of public health surveillance is to monitor important health outcomes and risk factors and provide actionable information to practitioners, policy makers, researchers, and the public to prevent or ameliorate exposure, disease, and death. Although separate 1970s-era acts of Congress made possible the creation of modern occupational health and environmental public health surveillance, these acts also led to fragmented responsibilities and unconnected data across federal agencies. Having a well-defined purpose for systematically collecting relevant data is key, and state and local programs play a crucial role in conducting meaningful surveillance and connecting it with evidence-based outreach and interventions. Congress has directed monies to environmental public health surveillance and capacity has improved, yet no analagous funding has occurred to address the fragmentation found within occupational health surveillance. This article provides a review of the advances and important themes within occupational health and environmental public health surveillance over the past decade.

INTRODUCTION

By traditional definition, public health surveillance is "the ongoing, systematic collection, analysis, and interpretation of outcome-specific data, closely integrated with the timely dissemination of these data to those responsible for preventing and controlling disease or injury" (123, p. 384). The essential purpose of public health surveillance is to monitor important health outcomes and risk factors and provide actionable information to practitioners (public health and clinical), policy makers, researchers, and the public to prevent exposure, disease, and death (75, 120, 122). Some have noted that the intent of public health surveillance must be more than simply providing statistics; it must also directly inform actions to improve the health of the population being monitored (9, 57, 65, 75, 121).

Although public health surveillance is considered a core service in public health, it is not designed to exist in isolation. Relevant, synthesized information from a public health surveillance system must be effectively communicated to the appropriate audiences. The basis of effective surveillance is the current and accurate two-way flow of information among all those who need to know (66). Policy makers, decision makers, and program officials must be given valuable information to enable the creation of policies, legislation, regulations, and programs focused on helping people lead safer and healthier lives. Practitioners need timely information to augment their knowledge base and enable them to take prompt action or design interventions to effect change. Researchers often use results derived from surveillance systems to demonstrate the need for an etiologic study of a disease, high-risk population, or apparent hazard.

The Creation of Multiple Responsible Agencies in the 1970s Offered Opportunities and Problems for Occupational Health and Environmental Public Health Surveillance

Although separate acts of Congress in the 1970s (e.g., the Clean Air Act, the OSH Act, the Safe Drinking Water Act) made possible the creation of modern occupational health and environmental public health surveillance, these acts have also created challenges for effective occupational health and environmental public health surveillance today. The Occupational Safety and Health (OSH) Act of 1970 made the Department of Labor responsible for collecting statistics on occupational injuries and illnesses as well as hazard and exposure data and designated the Department of Health, via the National Institute for Occupational Safety and Health (NIOSH), to be relied on for conducting research to inform the setting of standards and regulations. Separate congressional legislation created the U.S. Environmental Protection Agency and gave it the responsibility to oversee the monitoring of environmental pollutants. Meanwhile, the Centers for Disease Control and Prevention would continue its work in capturing information on health outcomes.

Tracking Chronic Exposures and Diseases Provides Unique Challenges

Public health surveillance as a distinct discipline developed especially within the domain of specific disease outcomes. Creating and using clear case definitions became the standard practice in public health surveillance, and causal agents were identified as medical science and epidemiology advanced and converged. The time between exposure and symptom onset for most communicable diseases is acute and measured in hours or days. Public health surveillance for infectious diseases became widely practiced and accepted within public health agencies, and its uses and value became well established during the twentieth century.

The proximity between the time of exposure and clinical disease may be months or years for environmental or occupational exposures. This delay causes both practical and theoretical challenges in conducting occupational health and environmental public health surveillance.

Other authors have reviewed many aspects of occupational health and environmental public health surveillance, including the many data sources involved (77, 115, 116). In this review, we offer what we consider to be important themes in contemporary occupational health and environmental public health surveillance. We furnish some informative examples of these themes and identify a number of consequential challenges to contemporary occupational health and environmental public health surveillance.

CONCEPTUAL MODELS OF HOW OCCUPATIONAL HEALTH AND ENVIRONMENTAL PUBLIC HEALTH SURVEILLANCE CONTRIBUTE TO IMPROVED HEALTH OUTCOMES

How the domains of occupational health and environmental public health currently pursue the monitoring, analyzing, and reporting of information to recipients of that information is significantly influenced by the theory and optimism of future public health surveillance that was prevalent in the latter part of the twentieth century. Understanding the conceptual models of how occupational health and environmental public health surveillance presently attempt to contribute to improved health outcomes is critical to discerning why these efforts have been (or have fallen short of being) effective.

Occupational Health Surveillance

In the 1980s, the concept of "sentinel health events" was put forward and formalized within occupational health surveillance (9, 112). A sentinel health event within occupational health was defined to be

> an unnecessary disease, disability, or untimely death which is occupationally related and whose occurrence may: 1) provide the impetus for epidemiologic or industrial hygiene studies; or 2) serve as a warning signal that materials substitution, engineering control, personal protection, or medical care may be required. (112, p. 1055)

Rutstein et al. (112) offered a list of 50 occupationally related conditions and their corresponding International Classification of Diseases (ICD)-9 codes as a tool for surveillance and for use by physicians and as an enumeration of current important occupationally related diseases. This list of sentinel health events was also intended to serve as the basis for a national occupational health surveillance system in the United States. Efforts within the occupational health community ultimately led to the creation of the Sentinel Events Notification System for Occupational Risks (SENSOR) program. Much of contemporary occupational health surveillance is based on this sentinel health event approach.

Halperin (57) and Maizlish (75) offered models of the relationships between occupational health surveillance and prevention through workplace controls and safety measures (**Figure 1**).

Environmental Public Health Surveillance

As investigators learned from the recent initiatives within occupational health surveillance (2, 124), the theory of modern environmental public health surveillance arose in the 1990s. A number of influential papers and reports noted that environmental health surveillance was fragmented in the United States and creating a comprehensive national environmental public health surveillance system could be highly beneficial. By bringing together data from the various existing data-collection systems of environmental pollutants and disease outcomes and analyzing those linked data in appropriate ways, more light may be shed on the contribution of environmental pollutants to chronic diseases (94, 124).

Thacker et al. (124) offered a model of the steps of how an environmental agent can cause clinical symptoms and disease with corresponding opportunities for surveillance (**Figure 2**). Hazard surveillance of environmental agents should inform interventions and primary prevention efforts, exposure surveillance should help evaluate hazard-reduction efforts and inform secondary prevention activities,

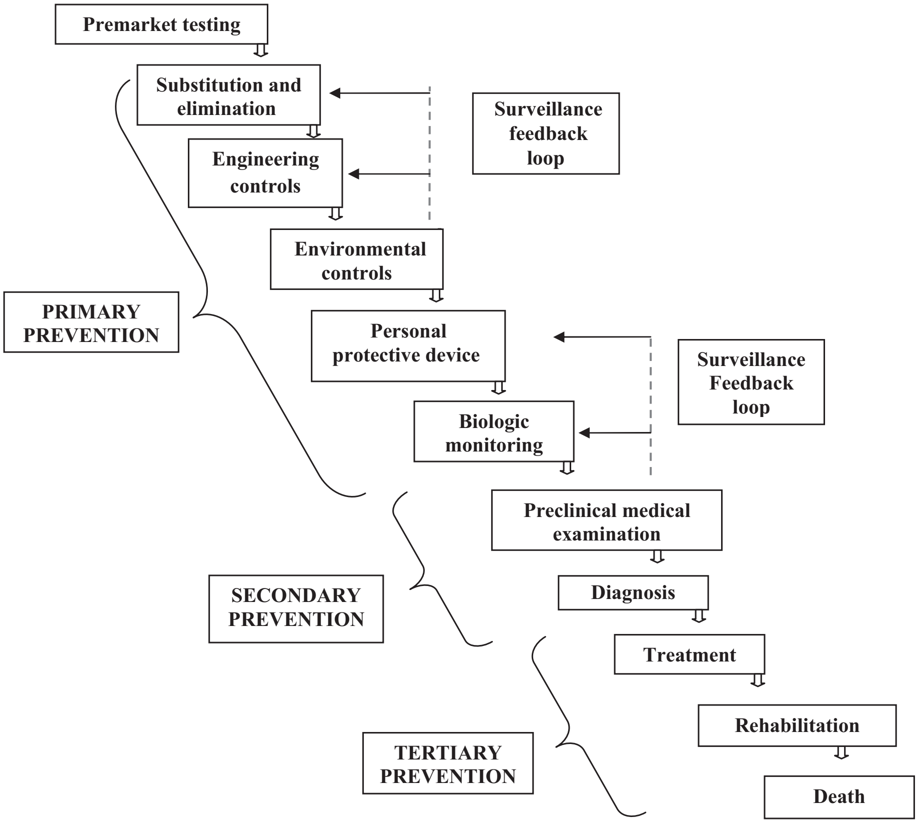

Figure 1

Surveillance and prevention for occupational health. Adapted from Maizlish (75) and Halperin (57).

and outcome surveillance should monitor the burden of disease and enable the analysis of specific hazards/exposures against outcomes. Thacker et al. (124) identified 19 different national data sources that "support environmental public health surveillance" (p. 635).

The Pew Environmental Health Commission reports from 2000 (93, 94) have been very influential on subsequent environmental public health surveillance program efforts in the United States. These reports called for the creation of a nationwide health tracking network with (*a*) baseline tracking of diseases and exposures, (*b*) a national early warning system, (*c*) state tracking programs, (*d*) the ability to conduct public health investigations, and (*e*) responsiveness to community and research needs. Although much of the Commission's recommendations called for functions typical to public health surveillance systems, other services of the proposed network included answering fundamental questions on the relationships between environmental hazards and chronic diseases, being "grounded in community groups," and meeting the public's "right to know" by disseminating information at the local and community levels (93, p. 9; 94). Implementing such a comprehensive network could, of course, be very challenging.

More recent papers have offered very useful ideas on how effective environmental public health surveillance should be pursued. Kyle et al. (64) describe how using and advancing our scientific knowledge base could greatly support and complement the intent of public health surveillance, providing information

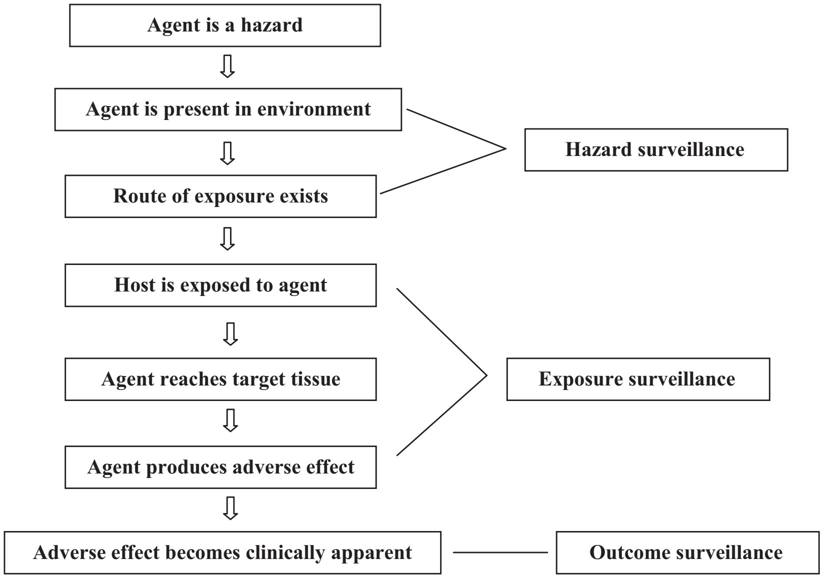

Figure 2

Model of hazard, exposure, and outcome. Adapted from Thacker et al. (124).

to those who need to know for disease prevention. Kass et al. (61) used feedback from a stakeholder advisory group to help identify seven principles to guide their decision making in the development of a tracking system. These principles included making good use of existing data and resources, linking "data in scientifically valid and defensible ways" (p. 1420), considering the needs of a variety of users, and having an explicit goal of informing intervention efforts.

HAVING A CLEAR PURPOSE AND EMPIRICAL EVIDENCE MAKES A DIFFERENCE

Two keys to effective surveillance within occupational health and environmental public health are (*a*) having a well-defined purpose for collecting the data and then (*b*) having the data to make some meaningful analyses possible. We use the examples of childhood blood lead surveillance and pesticide poisoning surveillance to demonstrate this theme in contemporary occupational health and environmental public health surveillance.

The Centers for Disease Control and Prevention's Childhood Lead Poisoning Prevention Program seeks to eliminate childhood lead poisoning in the United States by advancing effective programs and policies, educating the public and health care providers, providing funding to state and local partners, and supporting research to evaluate the effectiveness of federal, state, and local efforts (32). The program has specific goals for its Childhood Lead Poisoning Surveillance system at both the state/local and national levels (84). Surveillance at the state/local level focuses on case management and planning and evaluation of prevention initiatives by the state/local authorities and its partners. By identifying lead exposure sources and targeting prevention in high-risk areas within the state and local boundaries, lead exposure in children can be prevented and subsequent health effects can be avoided. At the national level, the goals of the surveillance system include (*a*) monitoring the nation's progress on eliminating childhood lead poisonings, (*b*) tracking the number of lead-poisoned children to prioritize the use of federal resources, (*c*) evaluating the efficacy of the Centers for

Disease Control and Prevention's (CDC) grant program, (*d*) assessing the effectiveness of state prevention efforts, and (*e*) tracking national trends in sources of lead to which children are being exposed.

Over time, the Childhood Lead Poisoning Surveillance has successfully documented the magnitude and trends of elevated blood lead levels for the United States and most states. It has helped to identify lead-based paint in housing; lead exposure in home renovation, repair, and painting activities; lead in contaminated soil and dust; lead in tap water; lead in imported children's toys/charms; high-risk immigrant groups; indoor firearm ranges; and ethnic remedies as sources of childhood lead poisonings in various communities. Children under age six are especially at risk, and impoverished children living in older housing have the greatest danger for lead exposure. Effective methods for the targeted testing of children based on community-level risk factors have been developed and implemented for state/local child lead prevention programs.

SENSOR–Pesticides is a state-based program coordinated by NIOSH whose purpose is to track cases of pesticide-related injuries and illnesses and to use that information to minimize the number of future pesticide poisonings in workers and nonworkers alike (27). The program uses a clear, standardized case definition, and states receive case reports from three primary sources: poison control centers, workers' compensation insurance companies, and state regulatory agencies responsible for pesticide regulation (generally, the state department of agriculture). The participating states, of which there were 12 in 2010, analyze the data at the state level and disseminate the findings to stakeholders for the purpose of targeting public health interventions. The data are also aggregated by NIOSH into a national dataset. NIOSH regularly undertakes multistate analyses and generates reports. As a result, the SENSOR–Pesticides program has succeeded in identifying industries, occupations, and activities at high risk for acute pesticide poisoning.

The program has had several impacts. For example, after the publication of a paper that documented the magnitude of acute pesticide poisoning associated with pesticide exposures at schools in 2005, at least five states have passed rules or laws requiring or recommending Integrated Pest Management (IPM) in schools statewide (1). Some emerging issues have been identified through SENSOR–Pesticides. For example, federal, state, and local authorities investigated three cases of infants born with congenital anomalies whose mothers worked at the same grower's farms during the first eight weeks of their pregnancies, the time in which an embryo's organs are formed (26). During the first eight weeks of their pregnancies, all three mothers appear to have worked in fields recently treated with pesticides in violation of federal and state pesticide regulations. Subsequently, in 2008, the state legislature in North Carolina passed antiretaliation and record-keeping laws, training mandates to protect the health of agricultural workers, and funding for improved surveillance (25).

STATE AND LOCAL PROGRAMS PLAY A CRITICAL ROLE

Another theme of contemporary occupational health and environmental public health surveillance is the critical role state and local surveillance programs continue to play in conducting meaningful surveillance, in tandem with conducting evidence-based outreach and interventions (66). State and local programs are positioned to understand the occupational health and environmental public health needs within their jurisdictions and to use the information obtained from public health surveillance to coordinate prevention efforts in communities and target populations. Acceptability, the willingness of persons and organizations to participate in a surveillance system, is a key attribute of a public health surveillance system (54, 62). State/local programs often appreciate the cultural and societal influences that determine whether communities, industries, or occupations support and buy into the monitoring of hazards, exposures, and/or health outcomes within their populations.

State and local programs have provided a multitude of recent examples of effective occupational health and environmental public health surveillance (5, 6, 11, 15–17, 20, 22–24, 28, 33, 34, 44, 49–51, 58, 59, 61, 63, 73, 74, 80, 88, 92, 97–104, 106, 107, 110, 111, 118, 125–128, 136, 137).

As one example, the Washington State Safety and Health Assessment and Research for Prevention (WA-SHARP) program initiated efforts to prioritize their research and prevention activities through a data-driven approach in the beginning part of the current decade (130). They realized that an industry-based approach might be useful, given that multiple health end points could be tracked in such an approach. When tracking multiple end points within an industry, the link to prevention from the employer viewpoint was potentially more acceptable. By selecting an industry and focusing on work-related musculoskeletal disorders, fall injuries, being struck by objects, being caught in or under objects, or vehicular crashes, WA-SHARP investigators were able to account for a major portion of workplace injuries that resulted in time loss workers compensation claims. The WA-SHARP program identified seven major injury types that accounted for 90% of all compensable claims (also known as time loss claims), 90% of state fund compensable claim costs, and 90% of state fund time loss days (14).

Lacking any national occupational health surveillance system to provide occupational health practitioners the necessary data, a number of state projects have combined data from different sources and used data linkage methods to obtain estimates within their respective states (21, 46, 67, 105, 117). Using such an approach, State of Michigan officials found that the agriculture, manufacturing, and construction industries had the highest rates of work-related amputations within their state for that year (117).

THE EMERGENCE OF PUBLIC HEALTH INDICATORS

Developing and calculating public health indicators have become important initiatives within both occupational health and environmental public health surveillance, and we consider this to be another important topic worth discussing. An indicator has been defined as "a construct of public health surveillance that defines a measure of health (i.e., the occurrence of a disease or other health-related event) or a factor associated with health (i.e., health status or other risk factor) among a specified population" (42, p. 67). There have been three significant environmental health indicator initiatives and one ongoing occupational health indicators initiative in the United States since the mid 1990s.

Occupational Health Indicators from CSTE/NIOSH

Beginning in 2001, a work group of state occupational health officials and CDC/NIOSH members developed a consensus approach to identify a set of occupational health indicators (36). The criteria for selecting the indicators were (*a*) availability of easily obtainable statewide data, (*b*) public health importance, and (*c*) potential for workplace intervention activities. After the group picked nineteen occupational health indicators and one employment demographics profile, five NIOSH-funded states then created specific guidelines for calculating each of these measures and pilot-tested the indicators. The Council of State and Territorial Epidemiologists (CSTE)/NIOSH collaboration produced an occupational health indicators report for 13 participating states using data from 2000 (42). Because the data-collection systems vary by state for some indicators (e.g., workers compensation), the work group consistently cautions against comparing one state against another for those indicators (41). NIOSH-funded state programs continue to submit these same 19 occupational health indicators to CSTE each year (39) (**Table 1**).

Table 1 CSTE/NIOSH occupational health indicators. Each indicator is intended to be calculated by state and year[a]

#	Indicator	Source of data	Type
1	Nonfatal injuries and illnesses reported by employers	BLS Annual Survey of Occupational Injuries and Illnesses (SOII)	O
2	Work-related hospitalizations	State hospital discharge data	O
3	Fatal work-related injuries	Census of Fatal Occupational Injuries (CFOI)	O
4	Amputations reported by employers	SOII	O
5	Amputations identified in state workers' compensation systems	State workers' compensation data	O
6	Hospitalizations for work-related burns	State hospital discharge data	O
7	Musculoskeletal disorders reported by employers	SOII	O
8	Carpal tunnel syndrome cases identified in state workers' compensation system	State workers' compensation data	O
9	Pneumoconiosis hospitalizations	State hospital discharge data	O
10	Pneumoconiosis mortality	State vital records	O
11	Acute work-related pesticide poisonings reported to poison control centers	American Association of Poison Control Centers	O
12	Incidence of malignant mesothelioma	State cancer registries	O
13	Elevated blood lead levels among adults	Adult Blood Lead Epidemiology Surveillance (ABLES) program	E
14	Workers employed in industries with high risk for occupational morbidity	Census Bureau County Business Patterns	H
15	Workers employed in occupations with high risk for occupational morbidity	Bureau of Labor Statistics Current Population Survey (CPS)	H
16	Workers in occupations and industries with high risk for occupational mortality	CPS	H
17	Occupational health and safety professionals	Current membership rosters of cited organizations.	I
18	OSHA enforcement activities	OSHA Office of Statistics	I
19	Amount of workers' compensation awards paid	National Academy of Social Insurance	S

[a]Abbreviations of types: H, occupational hazard; E, exposure; O, health outcome; I, intervention resource; S, socioeconomic impact.

Environmental Public Health Indicators Project

The Environmental Public Health Indicators (EPHI) Project was a joint collaboration among the CSTE, the CDC/National Center for Environmental Health (NCEH) and the Agency for Toxic Substances and Disease Registry (ATSDR), and the U.S. Environmental Protection Agency (EPA); the Association of State and Territorial Health Officials (ASTHO), the National Association of City and County Health Officials (NACCHO), and the Public Health Foundation (PHF) contributed as well (4). The EPHI Project identified a list of potential indicators for inclusion in a possible "national public health surveillance system" (83, 95). Although the EPHI Project did not create guidelines for calculating indicators, the project did identify possible data sources and proposed 15 hazard indicators, 1 exposure indicator, 11 health outcome indicators, and 14 intervention indicators (4, 29) (**Table 2**).

State Environmental Health Indicators Collaborative

Informed by the EPHI Project, the State Environmental Health Indicators Collaborative (SEHIC) had an initial goal "to convene a group of willing state level environmental health practitioners as collaborators to develop and

Table 2 Indicators proposed by the Environmental Public Health Indicators Project

Hazard indicators (potential for exposure to contaminants or hazardous conditions)
Criteria pollutants in ambient air
Hazardous or toxic substances released in ambient air
Residence in nonattainment areas (for criteria air pollutants)
Motor vehicle emissions
Tobacco smoke in homes with children
Residence in a flood plain
Pesticide use and patterns of use
Residual pesticide or toxic contaminants in foods
Ultraviolet light
Chemical spills
Monitored contaminants in ambient and drinking water
Point-source discharges into ambient water
Contaminants in shellfish and sport and commercial fish
Exposure indicator (biomarkers of exposure)
Blood lead level (in children)
Health effect indicators (occurrence of morbidity or mortality attributed to exposure)
Carbon monoxide poisoning
Deaths attributed to extremes in ambient temperature
Lead poisoning (in children)
Noise-induced hearing loss (nonoccupational)
Pesticide-related poisoning and illness
Illness or condition with suspected or confirmed environmental contribution (a case or an unusual pattern)
Melanoma
Possible child poisoning (resulting in consultation or emergency department visit)
Outbreaks attributed to fish and shellfish
Outbreaks attributed to ambient or drinking water contaminants
Intervention indicators (programs or official policies addressing environmental hazards)
Programs that address motor vehicle emissions
Alternate fuel use in registered motor vehicles
Availability of mass transit
Policies that address indoor air hazards in schools
Laws pertaining to smoke-free indoor air; indoor air inspections
Emergency preparedness, response, and mitigation training programs, plans, and protocols
Compliance with pesticide application standards (among pesticide workers)
Activity restrictions in ambient water (health-based)
Implementation of sanitary surveys
Compliance with operation and maintenance standards for drinking water systems
Boil-water advisories

compare indicators for use within environmental health surveillance and practice" (37). SEHIC members first set out to develop and pilot indicators on drinking water, air quality, and asthma (37) and later also created indicator work groups on climate change, air quality and respiratory morbidity, and vector-borne disease (40, 76). SEHIC work groups successfully developed an approach for using environmental public health indicators at the state level along with templates and detailed how-to guides (borrowing from the CSTE/NIOSH occupational health indicator initiative) to enable states to calculate the SEHIC indicators.

Environmental Public Health Tracking Indicators

With a 2002 mandate from the United States Congress, the Centers for Disease Control and Prevention (CDC) began overseeing the development of a comprehensive environmental public health tracking (EPHT) network to mount an effective national response to environmentally mediated acute and chronic disease "outbreaks." The CDC developed the infrastructure, resources, and methods for assembling and presenting available hazard, exposure, and health indicator data to public health professionals, researchers, and the public to improve the health and welfare of communities across the nation.

In May 2008, the 17 states and New York City funded by the CDC for EPHT participated in providing data to the CDC that was incorporated into a national public portal of the EPHT network, which launched in October 2009 (**http://www.cdc.gov/nceh/tracking/**). The data for the national EPHT portal initially provides county-specific information for core indicators in eight areas of environmental hazards and health indicators: water quality, air quality, myocardial infarction, asthma, carbon monoxide poisonings, childhood and other cancers, birth defects, and reproductive/birth outcomes (**Table 3**). Additionally, funded states are establishing state-specific EPHT portals, which will provide less aggregated hazard, exposure, and health indicator data to permit ongoing environmental public health tracking. Six additional states were added to the tracking program in 2010.

VALID METHODS AND USEFUL TOOLS ARE IMPORTANT

Another theme worth noting is the value new methods and useful tools have brought to modern occupational health and environmental public health surveillance. A number of statistical methods have been developed for monitoring public health surveillance data and have been covered in detail by Brookmeyer & Stroup (18). Geostatistics, which deals with spatial data, is applicable broadly to environmental public health surveillance data that are collected either as points referenced or else associated with an areal unit (7). Consider, for example, the air-quality monitoring in the United States that is based on a network of monitoring stations that are located largely in mainly urban areas. How one infers the values at points or blocks (points averaged over blocks) differs from using only observed monitored data points. This is known as a "change of support problem" in geostatistics (134). If the data are collected only at areal levels and inference is desired at new areal levels, the problem is referred to as a "modifiable area unit problem" (68). An additional problem arises if the environmental health surveillance indicators need to be analytically related to health and socio-demographic variables that are also measured at different spatial resolutions. A fruitful approach to solving the change of support problem has been to apply Bayesian statistical methodology either alone or in combination with geostatistical methods (10).

A useful application of Bayesian analysis has been one that combines output from Bayesian models and numerical computations to produce reliable information on environmental indicators of interest. One example is the spatial predictions from an analysis based on hierarchical Bayesian models for fine particulate matter that combines U.S. EPA federal Reference Method $PM_{2.5}$ monitoring data and Community Multiscale Air Quality numerical model output (82). The space-time hierarchical Bayesian model has also been used to fuse daily not only fine particulate air [24-h average but also daily ozone (8-h maximum)]. These predictive surfaces are available for both 12 km (Eastern United States) and 36 km (conterminous United States) and can be downloaded from the Web (**http://www.epa.gov/esd/land-sci/lcb/lcb_sfads.html**).

Table 3 CDC Environmental Public Health Tracking Network Indicators: as of April 2010: National CDC Public Portal. Each indicator is intended to be calculated by county and year. [See http://ephtracking.cdc.gov/showIndicatorsData.action (representative by category).[a]]

1. **Ambient air-quality indicators by county:**
    a. Annual $PM_{2.5}$ level
    b. Ozone days above regulatory standard
    c. $PM_{2.5}$ days above regulatory standard
2. **Asthma/myocardial infarction hospitalizations by county**
    a. Age-adjusted rate of hospitalization for asthma per 10,000 population
    b. Number of hospitalizations for asthma
    c. Average daily number of hospitalizations for asthma by month
    d. Crude rate of asthma hospitalizations among persons 35+ per 10,000
    e. Annual age-adjusted rate of hospitalizations for myocardial infarction among persons 35+ per 10,000
    f. Average number of hospitalizations by month for myocardial infarction
3. **Birth defects by county by year (denominator is all live born infants of interest during a calendar year per 10,000 live births over a five-year period)**
    a. Prevalence of anencephaly
    b. Prevalence of cleft lip with or without cleft palate
    c. Prevalence of cleft palate without cleft lip
    d. Prevalence of gastroschisis
    e. Prevalence of hypoplastic left heart syndrome
    f. Prevalence of hypospadias
    g. Prevalence of lower limb deficiencies
    h. Prevalence of spina bifida with or without anencephaly
    i. Prevalence of tetralogy of fallot
    j. Prevalence of transposition of the great arteries
    k. Prevalence of Trisomy 21
    l. Prevalence of upper limb deficiencies
4. **Cancer incidence by county (annual age-adjusted incidence rates per 100,000) and annual number of cases for selected cancers for**
    a. Acute myeloid leukemia
    b. Bladder cancer
    c. Brain and other nervous system cancer
    d. Breast cancer (females only)
    e. Chronic lymphocytic leukemia
    f. Leukemia
    g. Lung and bronchus cancers
    h. Non-Hodgkin's lymphoma
    i. Thyroid cancers
5. **Carbon monoxide poisoning by county by year**
    a. Total number of carbon monoxide poisonings: emergency department visits
    b. Age-adjusted rate of emergency department visits for carbon monoxide poisoning per 100,000 population
6. **Childhood cancers (average annual rate by county for children under the age of 20) per 1,000,000 per year**
    a. Incidence of acute lymphocytic leukemia
    b. Incidence of acute myeloid leukemia
    c. Incidence of brain and central nervous system cancer
    d. Incidence of leukemia

(*Continued*)

Table 3 (*Continued*)

7.	**Childhood Lead Poisoning (percent elevated greater than 10 ug/dl by county)**
	a. Blood lead levels by birth cohort
	Blood lead testing and housing age:
	b. Number of children born in the same year and tested for lead before age three
	c. Percent of children born in the same year tested for blood lead before age three
	d. Number of homes built before l950 by county as measured in 2000 Census
	e. Number and percentage of homes built between 1950 and 1979 measured by 2000 Census
8.	**Community water indicators**
	Arsenic
	a. Distribution of number of community water systems by mean arsenic concentrations (micrograms per liter) by three-year compliance period
	b. Distribution of number of people served by community water systems by mean arsenic concentration (micrograms per liter) by three-year compliance period
	Public water use
	c. Number of people receiving water from community water systems
	Disinfection By-Products—haloacetic acids
	d. Distribution of number of people served by community water systems by mean haloacetic acids concentrations (micrograms per liter)
	e. Distribution of number of community water systems by mean haloacetic acids concentrations (micrograms per liter) by year
	f. Quarterly distribution of number of people served by community water systems by mean haloacetic acids concentrations (micrograms per liter)
	Disinfection by-products—trihalomethanes
	g. Distribution of number of people served by community water systems by mean trihalomethane concentrations (micrograms per liter)
	h. Quarterly distribution of number of people served by community water systems by mean trihalomethane concentrations (micrograms per liter)
	i. Distribution of number of community water systems by mean trihalomethane concentrations (micrograms per liter) by year
	Nitrates
	j. Distribution of max nitrate concentrations (mg/L) by number of community water systems
	k. Distribution of mean nitrate concentrations (mg/L) by number of community water systems
	l. Distribution of number of people served by community water systems by maximum nitrate concentrations (mg/L)
	m. Distribution of number of people served by community water systems by mean nitrate concentrations (mg/L)
	Well water
	n. Domestic well water use by county
	o. Levels of contaminants in domestic (self-supplied) well water
9.	**Reproductive and birth outcomes by county per year**
	a. Growth retardation among singleton births
	b. Prematurity among singleton births
	c. Sex ratio

[a]For details concerning calculation measurements or definitions, please refer to the CDC Web site above.

Another approach to spatial prediction is Bayesian kriging, which effectively handles uncertainty in parameter estimation. In previous geostatistical approaches to spatial prediction using kriging, the covariance structure was estimated first and then the estimated covariance was used for interpolation. The properties of the interpolants based on an estimated covariance structure are poorly understood, and the general tendency has been to discount the effect of the uncertainty in the covariance structure on ensuing predictions. A Bayesian approach to interpolation of spatial processes has provided a general methodology for taking into account the uncertainty about parameters on subsequent predictions.

Zhu et al. (135) showed how hierarchical spatial regression modeling can be used to analyze a dataset relating several air quality indicators (ozone, particulate matter, nitrogen oxides, etc.) and a range of sociodemographic variables (age, gender, race, and a socioeconomic status surrogate) to a response: pediatric emergency department (ED) visit counts for asthma in Atlanta, Georgia. The air quality data are point referenced, whereas the socio-demographic covariates and response variable are collected by zip code.

Surveillance databases are often large, complex, and multidimensional in nature; therefore, the availability of software tools and methods for analysis of data on an ongoing basis can be essential to a surveillance system. Desktop geographic information systems are now powerful enough in terms of memory, storage capacity, and speed to generate quickly and easily maps of environmental and disease risks (43). Investigators have begun to use satellite imagery in environmental public health surveillance, and the raster data format is ideal for processing such images (52).

The availability of free geospatial resources on the Internet has been a boon to the rapid diffusion of geographic information systems (GIS) tools. In particular, the standardization of geographical hierarchy with associated Federal Information Processing Standards (FIPS) codes (126) has allowed the census databases to be spatially linked to various GIS layers quickly and easily. The U.S. EPA has also made several surveillance databases available to the public in a database or spatial format (**http://www.epa.gov/enviro/**).

Although GIS continues to be underutilized within occupational health surveillance, other modern tools have been put to good use within this field. The approach of using multiple datasets to obtain more complete case-capture has been studied and effectively used in various instances (13, 48, 106). Capture-recapture has been successfully used to obtain more complete estimates of workplace injuries and illnesses and to assess the undercount of individual surveys (86, 105).

RESOURCES MATTER

Subsequent to the Pew Commission's recommendation to create a Nationwide Health Tracking Network and provide $275 million to fund 50 states, Congress began to allocate funds for a National Environmental Public Health Tracking Network in 2002. Congress initially provided $17.5 million per year to be administered by the CDC; this amount has since grown to $33 million per year in 2010, a portion of which funds 22 states and New York City. These funds have made significant impacts on investigators' capacity to conduct environmental public health surveillance within the funded states in the United States (72). With more than 20 environmental public health tracking and disease surveillance programs having been initiated at the regional, state, and local health department levels, the National Environmental Public Health Tracking Network (EPHTN) represents perhaps the first coordinated effort to address the relationship between environmental insults and chronic disease nationwide.

During this same period, occupational health surveillance has not received any analogous funding from Congress to create a comprehensive nationwide occupational health tracking network to address the many challenges of tracking injuries and illnesses in U.S. workers. The epidemiology and surveillance capacity of state and territorial occupational health programs in the United States has been and continues to be very poor; most states report minimal to no capacity (38). As an example, the goal of the Adult Blood Lead Epidemiology and Surveillance program is to monitor and effectively prevent lead overexposures in the United States (89), yet the average annual funding for a state program in 2009 was approximately $20,000 (90). In **Tables 4** and **5**, we address the extent of coverage provided by

Table 4 Examples of multistate environmental public health surveillance systems[a]

Name of surveillance system/program	Responsible organization	Tracked measure(s)	States participating	% U.S. population covered[b]
AIRNow	EPA	Air Quality Index	All	**100%**
CDC's Childhood Lead Poisoning Prevention Program	CDC/NCEH	Childhood blood lead levels	All	**100%**
Environmental Public Health Tracking	CDC/NCEH	EPHT indicators (see **Table 3**)	CA, CO, CT, FL, KS, LA, ME, MD, MA, MN, MO, NH, NJ, NM, NY, NYC, OR, PA, SC, UT, VT, WA, WI	**54%**
National Toxic Substances Incidence Program	CDC/NCEH	Hazardous substance events and illnesses	OR, UT, WI, NY, TN, NC, LA	**16%**

[a]Abbreviations: CDC, Centers for Disease Control and Prevention; EPHT, environmental public health tracking; NCEH, National Center for Environmental Health.
[b]Source: U.S. Census Bureau: American Community Survey: 2006–2008 national and state population estimates.

different surveillance systems as varied by system and by which states are included.

PUBLIC HEALTH SURVEILLANCE SYSTEMS ARE DESIGNED FOR PRACTICE BUT ALSO SERVE RESEARCH

In addition to public health practice, public health agencies sometimes conduct research to gain necessary insight into the cause(s) of disease and risk factors or the efficacy of intervention methods. Relevant to public health agencies or their representatives conducting surveillance, the U.S. Department of Health and Human Services' Title 45 Code of Federal Regulations Part 46 (45 CFR 46) addresses the ethical issues in research involving human subjects (47). Surveillance systems and disease registries have been useful to both public

Table 5 Examples of multistate occupational health surveillance systems

Name of surveillance system	Measures	States participating	% of U.S. workforce covered[a]
Adult Blood Lead Epidemiology and Surveillance (ABLES)	Elevated blood lead	AK, AL, AZ, CA, CT, FL, GA, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MT, NC, NE, NH, NJ, NM, NY, OH, OK, OR, PA, RI, SC, TN, TX, UT, VT, WA, WI, WY	**91%**
SENSOR–Pesticides	Pesticide poisonings	CA, IA, MI, NY, TX, WA (funded); AZ, FL, LA, NC, NM, OR (unfunded)	**45%**
Fatality Assessment and Control Evaluation (FACE) Program	Case investigations for targeted fatalities	CA, OR, IA, KY, MA, MI, NJ, NY, WA	**32%**
State-Based Occupational Health Surveillance in Work-Related Asthma	Work-related asthma cases	CA, MA, MI, NJ	**19%**
State-Based Occupational Health Surveillance in Silicosis	Silicosis cases	MI, NJ	**6%**

[a]Source: Bureau of Labor Statistic—Occupational Employment Statistics: May 2009 release of national and state employment from all occupations.

health practice and research, and a public health agency is sometimes faced with the question of whether an analysis or project should be deemed "research." If a project is deemed research, it must be submitted to the organization's Human Subjects Review Board (HSRB); if it is unclear whether a project or analysis is research, it can be submitted to an HSRB to let the board make a determination.

Diligent to protect human subjects, the CDC created a human subjects review board in the 1980s and developed an initiative in 1997 to help "develop a strategic vision for improving its human subjects protection system" (113, p. 2). To provide some written guidance on interpreting 45 CFR 46 to both the organization and its staff, CDC's Office for Protection from Research Risks created *Guidelines for Defining Public Health Research and Public Health Non-Research* (30). These guidelines recognized surveillance, emergency response, and program evaluation as the types of activities within CDC that may be the most difficult to classify as either research or public health practice. Although each activity must be judged on a case-by-case basis, "The major difference between research and nonresearch lies in the primary intent of the activity" (30, p. 1). If an activity's major intent is to improve the health of the same "clients" or same population of people or to improve a service to that population, then the activity is public health practice. If the primary purpose of the activity is "to develop or contribute to generalizable knowledge" (47) and apply that knowledge to other populations, then the activity is research. The CDC guidelines note that disease reporting or data collection performed via a recognized public health authority, such as a state health department, are usually not considered to be research. These guidelines have been recently updated in the form of a CDC policy document (31).

Researchers in both public health agencies and academia may benefit from empirically derived hypotheses (also known as a posteriori) that are generated from cross-sectional analyses of surveillance systems data. They can then formulate subsequent studies (e.g., a case-control or cohort study) to test the hypothesis a priori. For example, Xu et al. (133) demonstrated that existing secondary data can be an economical source to assess the impact of point source polluters on the environmental landscape. They evaluated the impact of the closing in 1998 of a Pittsburgh, Pennsylvania, coking facility on cardiovascular and respiratory disease hospitalizations in the elderly before and after closure (1996–2000) using existing hospital admission, air pollution, and climatic data. Data were analyzed using a case-crossover design, and the results showed significant associations between the highest levels of PM_{10} and cardiorespiratory hospitalizations (OR: 1.13; 95% CI: 1.01–1.26) before the plant closure. After closure of the plant, PM_{10} was not significantly associated with cardiorespiratory or cardiovascular disease hospitalizations. Moreover, other academic centers of excellence in EPHT have joined with CDC tracking states to consider specific regional environmental health concerns such as the relationship between air quality and adverse birth outcomes (129).

The information needs of practitioners and decision makers are perhaps best met by complementing information from an established knowledge base, ongoing surveillance, and research.

OTHER IMPORTANT ACTIVITIES

Corporate monitoring, medical surveillance, environmental monitoring, and a number of individual surveys play a significant role in providing useful information for the purposes of prevention and decision-making (3, 12, 56, 87, 96, 109, 138). The National Health and Nutrition Examination Survey has provided national-level estimates of the biomarkers of exposure for many chemicals in the U.S. population. Corporations, government entities, and various workplaces often monitor the workplace for hazards and test workers for exposures and clinical measures of disease (45, 78, 79, 81, 96, 109). Lacking a nationwide occupational health surveillance system, occupational health researchers have often turned to supplemental surveys to fill basic information gaps on worker health. The National Health Interview Survey, the Behavioral Risk Factor Surveillance System, and the National Agricultural Workers Survey offer important examples of such supplements.

CURRENT CHALLENGES

Our last theme in occupational health and environmental public health surveillance is the current challenges. Although the cost of occupational injuries, illnesses, and deaths in the United States has been estimated to be between \$128 billion and \$155 billion per year (114), no comprehensive nationwide surveillance system exists to monitor workers' injuries and illnesses. The primary U.S. data source for worker illnesses and injuries is the Department of Labor's (DoL) annual Survey of Occupational Injuries and Illnesses (SOII), which collects data provided by responding employers. The shortcomings of this data source for the purposes of prevention and decision-making have been well documented since the 1980s (13, 35, 46, 55, 70, 71, 85, 86, 105, 117), but little has been done to change the fundamental problems of using an employer-based approach to capture workers' injuries and illnesses in the United States. The Occupational Safety and Health Act of 1970 explicitly excluded government workers (including firefighters and police officers), the self-employed, and many other workers from being included in the DoL's annual survey; this means ~1 in 5 workers were intentionally excluded. Beginning in 2008, DoL began to include state and local workers in the SOII (108). Beyond these exclusions by design, strong disincentives exist for both employers and workers alike not to report workplace injuries and illnesses (8, 60). Studies in one U.S. state have estimated the SOII missed ~2 out of 3 workplace injuries from 1999 to 2001 and 36% of the work-related amputations in the state during 1997 (105, 117). Many of the most vulnerable workers are the most likely not to have their workplace injuries captured by the SOII (116). This establishment-based survey performs largely as dictated by Congress in the Occupational Safety and Health Act of 1970 (70, 91, 108).

Most workplace hazard and exposure monitoring is done within corporate monitoring programs and by the Occupational Safety and Health Administration for the purposes of self-monitoring and regulatory compliance, respectively. Advocates in occupational health have called for better hazard and exposure surveillance to inform prevention and policy-making decisions within U.S. workplaces for decades (53, 131).

For environmental public health surveillance especially, taking advantage of health outcome data such as ED data, often available in electronic format and able to be deidentified, makes feasible a linkage between the hazard or environmental exposure and the outcome. ED visits and admissions, hospitalizations, and data from cancer registries, all offer significant potential for such ecological investigations. The combination of a deliberate and thoughtful consideration of a study's rationale, as well as adjustment for confounders, takes time and, unfortunately in the case of surveillance, these amenities are not always available. Many problems can be avoided if the age and gender distributions of a population are known and rates of disease as well as counts are able to be stratified and analyzed by age and gender. Moreover, plentiful and detailed census information on the area under study and careful consideration of the area of exposure will help ensure the most specificity of representation of the exposure to the exposed population (119).

Being able to identify emerging issues is an important function of a public health surveillance systems (19) and can be quite difficult to do; this remains a significant challenge within both occupational health and environmental public health surveillance. Investigators have offered one way to help identify emerging issues: Occupational and environmental health clinics should have a mechanism by which to communicate unusual findings, which could be coordinated centrally (69, 77, 132).

FUTURE ISSUES

1. Electronic health records must become capable of capturing a person's occupational history. Including clinical decision support systems within clinical practices could prompt clinicians to inquire about a patient's occupation and help prevent and/or diagnose work-related illnesses. Clinical decision support could apply to environmental exposures also, including prompting a clinician to test a child's blood lead level if the child resides in a community with known lead hazards.
2. The United States must confront the long-standing issue of undercounting injuries and illnesses in the workplace and address the need for accurate estimates to inform prevention efforts. Decision makers must commit to finding ways to enable effective hazard and exposure surveillance in the workplace in the United States.
3. Workers and the public should have access to comprehensible information on the hazards and exposures they face within their occupations, industries, and communities.
4. Impartial evaluations of individual occupational health or environmental public health surveillance systems should be performed by senior staff outside of the program being evaluated and across disciplines and then be made public (55). Expert panels could provide recommendations for improving surveillance systems, and advisory boards could help ensure large, developed programs are effective.
5. Topic-specific knowledge bases for practitioners and the public should be created and offered online to provide an information-foundation upon which surveillance activities are conducted and research studies are planned.
6. The creation of a journal dedicated to the science and practice of public health surveillance would serve the needs of the public health community. Such a journal could cover both the theoretical (e.g., models of how a system contributes to people's health/safety being improved) and the applied (e.g., improved approaches to case ascertainment, effective data linkages, enumeration of existing hazard/exposure/health surveillance systems, etc.) aspects of public health surveillance.
7. Decision makers must address the issue of some states consistently not receiving federal funds and having little to no capacity to conduct occupational health or environmental public health surveillance within their states. The National Environmental Public Health Tracking Network should include all states within the United States, and additional indicators should be added to meet stakeholder needs.
8. We must continue to develop practitioner-oriented user-friendly tools for linking and analyzing environmental and health-outcome data with particular focus on state-of-the-art spatial and statistical analysis methods.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

This work was partially funded by CDC grant number U19 EH000103-05. Although the authors are solely responsible for the shortcomings of this article, we thank the following people for providing helpful suggestions on the content of this review: Henry Anderson (Wisconsin Department of Health Services), Sherry Baron (CDC/NIOSH), Winifred Boal (CDC/NIOSH), David Bonauto (Washington), Terry Bunn (University of Kentucky), Richard Clapp (Boston University, School of Public Health), Jayanth Devasundaram (Pennsylvania Department of Health), Robert Harrison (University of California, San Francisco), Gregory Kearney (CDC/NCEH), Max Kiefer (CDC/NIOSH), Maureen Orr (CDC/ATSDR), Ken Rosenman (Michigan State University), John Sestito (CDC/NIOSH), and Rosemary Sokas (U.S. Department of Labor). Special thanks also go to SangWoo Tak (CDC/NIOSH), Kerry Souza (CDC/NIOSH), John Sestito (CDC/NIOSH), and Pam Meyer (CDC/OD) for their helpful suggestions on improving this article and to Hovi Ngyuen for his help with the figures and tables.

LITERATURE CITED

1. Alarcon WA, Calvert GM, Blondell JM, Mehler LN, Sievert J, et al. 2005. Acute illnesses associated with pesticide exposure at schools. *JAMA* 294:455–65
2. Aldrich TE, Leaverton PE. 1993. Sentinel event strategies in environmental health. *Annu. Rev. Public Health* 14:205–17
3. Amacher RW. 2007. Contributions of medical surveillance. *Occup. Health Saf.* 76:64, 6, 8–70 passim
4. Anderson H. 2001. *Development of environmental public health indicators*. Council of State and Territorial Epidemiologists (CSTE). **http://www.cste.org/ps/2001/2001-env-02.htm**
5. Anderson HA, Islam KM. 2006. Trends in occupational and adult lead exposure in Wisconsin 1988–2005. *Wis. Med. J.* 105:21–25
6. Anderson NJ, Bonauto DK, Adams D. 2010. Work-related amputations in Washington state, 1997–2005. *Am. J. Ind. Med.* 53(7):693–705
7. Atkinson PM, Lloyd CD, eds. 2009. *geoENV VII—Geostatistics for Environmental Applications*. Dordrecht: Springer. 384 pp.
8. Azaroff LS, Levenstein C, Wegman DH. 2002. Occupational injury and illness surveillance: conceptual filters explain underreporting. *Am. J. Public Health* 92:1421–29
9. Baker EL. 1989. Sentinel Event Notification System for Occupational Risks (SENSOR): the concept. *Am. J. Public Health* 79(Suppl.):18–20
10. Banerjee S, Carlin BP, Gelfand AE. 2004. *Hierarchical Modeling and Analysis for Spatial Data*. Boca: CRC/Chapman and Hall. 472 pp.
11. Bekkedal MY, Malecki KM, Werner MA, Anderson HA. 2008. Using a partnership barometer to evaluate environmental public health tracking activities. *J. Public Health Manag. Pract.* 14:592–95
12. Bertsche PK, Mensah E, Stevens T. 2006. Complying with a corporate global noise health surveillance procedure—do the benefits outweigh the costs? *AAOHN J.* 54:369–78
13. Boden LI, Ozonoff A. 2010. Researcher judgment and study design: challenges of using administrative data. *Am. J. Ind. Med.* 53:37–41
14. Bonauto D, Silverstein B, Adams D, Foley M. 2006. Prioritizing industries for occupational injury and illness prevention and research, Washington State Workers' compensation claims, 1999–2003. *J. Occup. Environ. Med.* 48:840–51
15. Bonauto DK, Keifer M, Rivara FP, Alexander BH. 2003. A community-based telephone survey of work and injuries in teenage agricultural workers. *J. Agric. Saf. Health* 9:303–17
16. Bonauto DK, Smith CK, Adams DA, Fan ZJ, Silverstein BA, Foley MP. 2010. Language preference and non-traumatic low back disorders in Washington State workers' compensation. *Am. J. Ind. Med.* 53:204–15
17. Bonauto DK, Sumner AD, Curwick CC, Whittaker SG, Lofgren DJ. 2005. Work-related asthma in the spray-on truck bed lining industry. *J. Occup. Environ. Med.* 47:514–17
18. Brookmeyer R, Stroup DF. 2004. *Monitoring the Health of Populations: Statistical Principles and Methods for Public Health Surveillance*. Oxford: Oxford Univ. Press. 390 pp.

19. Buehler JW, Hopkins RS, Overhage JM, Sosin DM, Tong V. 2004. Framework for evaluating public health surveillance systems for early detection of outbreaks: recommendations from the CDC Working Group. *MMWR Recomm. Rep.* 53:1–11
20. Bunn T, Costich J, Slavova S. 2006. Identification and characterization of Kentucky self-employed occupational injury fatalities using multiple sources, 1995–2004. *Am. J. Ind. Med.* 49:1005–12
21. Bunn TL, Slavova S, Bathke A. 2007. Data linkage of inpatient hospitalization and workers' claims data sets to characterize occupational falls. *J. Ky. Med. Assoc.* 105:313–20
22. Bunn TL, Slavova S, Hall L. 2008. Narrative text analysis of Kentucky tractor fatality reports. *Accid Anal. Prev.* 40:419–25
23. Bunn TL, Slavova S, Struttmann TW, Browning SR. 2005. Sleepiness/fatigue and distraction/inattention as factors for fatal versus nonfatal commercial motor vehicle driver injuries. *Accid. Anal. Prev.* 37:862–69
24. Bunn TL, Struttmann TW. 2003. Characterization of fatal occupational versus nonoccupational motor vehicle collisions in Kentucky (1998–2000). *Traffic Inj. Prev.* 4:270–75
25. Calvert GM, Higgins SA. 2010. Using surveillance data to promote occupational health and safety policies and practice at the state level: a case study. *Am. J. Ind. Med.* 53:188–93
26. Calvert GM, Petersen AM, Sievert J, Mehler LN, Das R, et al. 2007. Acute pesticide poisoning in the U.S. retail industry, 1998–2004. *Public Health Rep.* 122:232–44
27. Calvert GM, Plate DK, Das R, Rosales R, Shafey O, et al. 2004. Acute occupational pesticide-related illness in the US, 1998–1999: surveillance findings from the SENSOR-pesticides program. *Am. J. Ind. Med.* 45:14–23
28. Casteel C, Peek-Asa C, Nocera M, Smith JB, Blando J, et al. 2009. Hospital employee assault rates before and after enactment of the California Hospital Safety and Security Act. *Ann. Epidemiol.* 19:125–33
29. Cent. Dis. Control Prev. 2010. *Environmental public health indicators*. **http://www.cdc.gov/nceh/indicators/**
30. Cent. Dis. Control Prev. 1999. *Guidelines for Defining Public Health Research and Public Health Non-Research*. Atlanta: CDC/OPRR. **http://www.cdc.gov/od/science/integrity/hrpo/researchDefinition.htm**
31. Cent. Dis. Control Prev. 2010. *Distinguishing Public Health Research and Public Health Nonresearch*. Atlanta: CDC/OADS. **http://www.cdc.gov/od/science/integrity/docs/cdc-policy-distinguishing-public-health-research-nonresearch.pdf**
32. Cent. Dis. Control Prev. 2010. *CDC's childhood lead poisoning prevention program*. **http://www.cdc.gov/nceh/lead/about/program.htm**
33. Chan J, Janowitz I, Lashuay N, Stern A, Fong K, Harrison R. 2002. Preventing musculoskeletal disorders in garment workers: preliminary results regarding ergonomics risk factors and proposed interventions among sewing machine operators in the San Francisco Bay Area. *Appl. Occup. Environ. Hyg.* 17:247–53
34. Chester DA, Hanna EA, Pickelman BG, Rosenman KD. 2005. Asthma death after spraying polyurethane truck bedliner. *Am. J. Ind. Med.* 48:78–84
35. Comm. Gov. Oper., U.S. Congr. 1986. *Occupational Health Hazard Surveillance: 72 Years Behind and Counting: Sixty-First Report*. Washington, DC: GPO
36. Counc. State Territ. Epidemiol. (CSTE). 2002. Occupational health indicators for tracking work-related health effects and their determinants. *MMWR* 51:1073–74
37. Counc. State Territ. Epidemiol. (CSTE). 2006. *The State Environmental Health Indicators Collaborative* (*SEHIC*). **http://www.cste.org/pdffiles/2006/AboutSEHICforCSTE%205.25.pdf**
38. Counc. State Territ. Epidemiol. (CSTE). 2009. *National assessment of epidemiology capacity, findings and recommendations*. **http://www.cste.org/dnn/LinkClick.aspx?fileticket=%2BS%2FEEifgcbmM%3D&tabid=36&mid=1496**
39. Counc. State Territ. Epidemiol. (CSTE). 2010. *Occupational health indicators, introduction and guide to the data tables for occupational health indicators*. **http://www.cste.org/OH/OHmain.asp**
40. Counc. State Territ. Epidemiol. (CSTE). 2010. *The State Environmental Health Indicators Collaborative* (*SEHIC*). **http://www.cste.org/OH/SEHIC.asp**
41. Counc. State Territ. Epidemiol. (CSTE)/Natl. Inst. Occup. Saf. Health (NIOSH). 2004. *Occupational health indicators: a guide for tracking occupational health conditions and their determinants*. **http://www.cste.org/Assessment/ECA/pdffiles/ECAfinal05.pdf**

42. Counc. State Territ. Epidemiol. (CSTE)/Natl. Inst. Occup. Saf. Health (NIOSH). 2005. *Putting data to work: occupational health indicators from thirteen pilot states for 2000*. **http://www.cste.org/pdffiles/newpdffiles/CSTE_OHI.pdf**
43. Cromley EK, McLafferty SL. 2002. Geographic information systems. In *GIS and Public Health*, pp. 15–37. New York: Guilford
44. Curwick CC, Bonauto DK, Adams DA. 2006. Use of objective testing in the diagnosis of work-related asthma by physician specialty. *Ann. Allergy Asthma Immunol.* 97:546–50
45. Daugherty NM, Falk RB, Furman FJ, Aldrich JM, Hilmas DE. 2001. Former radiation worker medical surveillance program at rocky flats. *Health Phys.* 80:544–51
46. Davis L, Wellman H, Hart J, Cleary R, Gardstein BM, Sciuchetti P. 2004. A comparison of data sources for the surveillance of work-related carpal tunnel syndrome in Massachusetts. *Am. J. Ind. Med.* 46:284–96
47. Dep. Health Hum. Serv. 2009. *Title 45 Code of Federal Regulations Part 46*. **http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.htm**
48. Earle-Richardson GB, Brower MA, Jones AM, May JJ, Jenkins PL. 2008. Estimating the occupational morbidity for migrant and seasonal farmworkers in New York state: a comparison of two methods. *Ann. Epidemiol.* 18:1–7
49. English PB, Kharrazi M, Davies S, Scalf R, Waller L, Neutra R. 2003. Changes in the spatial pattern of low birth weight in a southern California county: the role of individual and neighborhood level factors. *Soc. Sci. Med.* 56:2073–88
50. Fan ZJ, Silverstein BA, Bao S, Bonauto DK, Howard NL, et al. 2009. Quantitative exposure-response relations between physical workload and prevalence of lateral epicondylitis in a working population. *Am. J. Ind. Med.* 52:479–90
51. Flattery J, Davis L, Rosenman KD, Harrison R, Lyon-Callo S, Filios M. 2006. The proportion of self-reported asthma associated with work in three States: California, Massachusetts, and Michigan, 2001. *J. Asthma* 43:213–18
52. Ford TE, Colwell RR, Rose JB, Morse SS, Rogers DJ, Yates TL. 2009. Using satellite images of environmental changes to predict infectious disease outbreaks. *Emerg. Infect. Dis.* 15:1341–46
53. Froines J, Wegman D, Eisen E. 1989. Hazard surveillance in occupational disease. *Am. J. Public Health* 79(Suppl.):26–31
54. German RR, Lee LM, Horan JM, Milstein RL, Pertowski CA, Waller MN. 2001. Updated guidelines for evaluating public health surveillance systems: recommendations from the Guidelines Working Group. *MMWR Recomm. Rep.* 50:1–35; quiz CE1–7
55. Gov. Account. Off. 2009. *Workplace safety and health: enhancing OSHA's records audit process could improve the accuracy of worker injury and illness data*. **http://www.gao.gov/new.items/d1010.pdf**
56. Grzywacz JG, Alterman T, Muntaner C, Gabbard S, Nakamoto J, Carroll DJ. 2009. Measuring job characteristics and mental health among Latino farmworkers: results from cognitive testing. *J. Immigr. Minor. Health* 11:131–38
57. Halperin WE. 1996. The role of surveillance in the hierarchy of prevention. *Am. J. Ind. Med.* 29:321–23
58. Henry JP, Williamson DM, Schiffer R, Wagner L, Shire J, Garabedian M. 2007. Investigation of a cluster of multiple sclerosis in two elementary school cohorts. *J. Environ. Health* 69:34–38
59. Islam KM, Anderson HA. 2006. Status of work-related diseases in Wisconsin: five occupational health indicators. *Wis. Med. J.* 105:26–31
60. Jajosky RA, Harrison R, Reinisch F, Flattery J, Chan J, et al. 1999. Surveillance of work-related asthma in selected U.S. states using surveillance guidelines for state health departments—California, Massachusetts, Michigan, and New Jersey, 1993–1995. *MMWR CDC Surveill Summ.* 48:1–20
61. Kass DE, Thier AL, Leighton J, Cone JE, Jeffery NL. 2004. Developing a comprehensive pesticide health effects tracking system for an urban setting: New York City's approach. *Environ. Health Perspect.* 112:1419–23
62. Klaucke D. 1992. Evaluating public health surveillance systems. In *Public Health Surveillance*, ed. WE Halperin, pp. 26–41. New York: Van Nostrand Reinhold
63. Knorr RS, Condon SK, Dwyer FM, Hoffman DF. 2004. Tracking pediatric asthma: the Massachusetts experience using school health records. *Environ. Health Perspect.* 112:1424–27

64. Kyle AD, Balmes JR, Buffler PA, Lee PR. 2006. Integrating research, surveillance, and practice in environmental public health tracking. *Environ. Health Perspect.* 114:980–84
65. Landrigan PJ. 1989. Improving the surveillance of occupational disease. *Am. J. Public Health* 79:1601–2
66. Langmuir AD. 1963. The surveillance of communicable diseases of national importance. *N. Engl. J. Med.* 268:182–92
67. Largo T, Rosenman K. 2009. *Work-related amputations in Michigan, 2007*. **http://www.oem.msu.edu/userfiles/file/Annual%20Reports/Amputations/2007%20MI%20WR%20amputations.pdf**
68. Lawson AB. 2009. *Bayesian Disease Mapping: Hierarchical Modeling in Spatial Epidemiology*. New York: CRC Press. 368 pp.
69. Lax MB, Keogh JP, Jeffery N, Henneberger PK, Klitzman S, et al. 1996. Lead poisoning in telephone cable strippers: a new setting for an old problem. *Am. J. Ind. Med.* 30:351–54
70. Leigh JP, Marcin JP, Miller TR. 2004. An estimate of the U.S. Government's undercount of nonfatal occupational injuries. *J. Occup. Environ. Med.* 46:10–18
71. Lipscomb HJ, Dement JM, Li L, Nolan J, Patterson D. 2003. Work-related injuries in residential and drywall carpentry. *Appl. Occup. Environ. Hyg.* 18:479–88
72. Litt JS, Wismann A, Resnick B, Dawson RS, Hano M, Burke TA. 2007. Advancing health and environmental disease tracking: a 5-year follow-up study. *Am. J. Public Health* 97:456–63
73. Little BB, Spalding S, Walsh B, Keyes DC, Wainer J, et al. 2009. Blood lead levels and growth status among African-American and Hispanic children in Dallas, Texas—1980 and 2002: Dallas Lead Project II. *Ann. Hum. Biol.* 36:331–41
74. Lutzker LA, Rafferty AP, Brunner WM, Walters JK, Wasilevich EA, et al. 2010. Prevalence of work-related asthma in Michigan, Minnesota, and Oregon. *J. Asthma* 47:156–61
75. Maizlish N. 2000. Introduction. In *Workplace Health Surveillance, An Action-Oriented Approach*, ed. N Maizlish, pp. 3–23. New York: Oxford Univ. Press
76. Malecki KC, Kyle AD, VanDerslice J, Thomsen C. 2007. *A collaborative, state-based approach to development, testing, and evaluating environmental public health indicators*. State Environmental Health Indicators Collaborative. **http://www.cste.org**
77. Markowitz SB. 2007. The role of surveillance in occupational health. In *Environmental and Occupational Medicine*, ed. W Rom, pp. 9–21. Philadelphia, PA: Lippincott Williams & Wilkins
78. Marsh GM, Callahan C, Pavlock D, Leviton LC, Talbott EO, Hemstreet G. 1990. A protocol for bladder cancer screening and medical surveillance among high-risk groups: the Drake Health Registry experience. *J. Occup. Med.* 32:881–86
79. Marsh GM, Leviton LC, Talbott EO, Callahan C, Pavlock D, et al. 1991. Drake Chemical Workers' Health Registry Study: I. Notification and medical surveillance of a group of workers at high risk of developing bladder cancer. *Am. J. Ind. Med.* 19:291–301
80. Mazurek JM, Filios M, Willis R, Rosenman KD, Reilly MJ, et al. 2008. Work-related asthma in the educational services industry: California, Massachusetts, Michigan, and New Jersey, 1993–2000. *Am. J. Ind. Med.* 51:47–59
81. McGinnis J, Bohnker B, Malakooti M, Riegodedios AJ, Mann M, Sack DM. 2004. Navy and Marine Corps malaria surveillance from the Navy Disease Reporting System and the Defense Medical Epidemiological Database (1997–2000). *Mil. Med.* 169:627–30
82. McMillan NJ, Holland DM, Morara M, Feng J. 2008. Combining numerical model output and particulate data using Bayesian space-time modeling. *Environmetrics* 21:48–65
83. Meriwether RA. 1996. Blueprint for a national public health surveillance system for the 21st century. *J. Public Health Manag. Pract.* 2:16–23
84. Meyer P. 2010. *Goals for childhood lead poisoning surveillance*. **http://www.cdc.gov/nceh/lead/training/surveillance/index.html**
85. Miller G. 2008. *Hidden Tragedy: Underreporting of Workplace Injuries and Illnesses, A Majority Staff Report*. Washington, DC: House Comm. Educ. Labor, 110th Congr.
86. Morse T, Dillon C, Kenta-Bibi E, Weber J, Diva U, et al. 2005. Trends in work-related musculoskeletal disorder reports by year, type, and industrial sector: a capture-recapture analysis. *Am. J. Ind. Med.* 48:40–49

87. Muller JG, Rudolph WG, Lieske JM, Hernandez JE, Jan MH, Kubiak G. 2007. Changes in B-readings over time in the United States Navy Asbestos Medical Surveillance Program. *J. Occup. Environ. Med.* 49:194–203
88. Nicholson VJ, Bunn TL, Costich JF. 2008. Disparities in work-related injuries associated with worker compensation coverage status. *Am. J. Ind. Med.* 51:393–98
89. Natl. Inst. Occup. Saf. Health (NIOSH). 2010. *Adult Blood Lead Epidemiology and Surveillance* (*ABLES*). **http://www.cdc.gov/niosh/topics/ABLES/ables.html**
90. Natl. Inst. Occup. Saf. Health (NIOSH). 2010. *Examples of ABLES full funding purchase orders*. **http://www.cdc.gov/niosh/topics/ABLES/ables.html**
91. Oleinick A, Zaidman B. 2010. The law and incomplete database information as confounders in epidemiologic research on occupational injuries and illnesses. *Am. J. Ind. Med.* 53:23–36
92. Pechter E, Davis LK, Tumpowsky C, Flattery J, Harrison R, et al. 2005. Work-related asthma among health care workers: surveillance data from California, Massachusetts, Michigan, and New Jersey, 1993–1997. *Am. J. Ind. Med.* 47:265–75
93. Pew. 2000. America's environmental health gap: why the country needs a nationwide health tracking network. *Companion Rep.*, Environ. Health Track. Proj. Team, Johns Hopkins Sch. Hyg. Public Health Dep. Health Policy Manag.
94. Pew. 2000. America's environmental health gap: why the country needs a nationwide health tracking network. *Tech. Rep.*, Pew Environ. Health Comm.
95. Pinner RW. 1998. Public health surveillance and information technology. *Emerg. Infect. Dis.* 4:462–64
96. Raymond LW, Wintermeyer S. 2006. Medical surveillance of workers exposed to crystalline silica. *J. Occup. Environ. Med.* 48:95–101
97. Roberts EM, English PB, Grether JK, Windham GC, Somberg L, Wolff C. 2007. Maternal residence near agricultural pesticide applications and autism spectrum disorders among children in the California Central Valley. *Environ. Health Perspect.* 115:1482–89
98. Roberts EM, English PB, Van den Eeden SK, Ray GT. 2006. Progress in pediatric asthma surveillance I: the application of health care use data in Alameda County, California. *Prev. Chronic. Dis.* 3:A91
99. Roberts EM, English PB, Wong M, Wolff C, Falade M. 2008. Spatially continuous local rate modeling for communication in public health: a practical approach. *J. Public Health Manag. Pract.* 14:562–68
100. Roberts EM, English PB, Wong M, Wolff C, Valdez S, et al. 2006. Progress in pediatric asthma surveillance II: geospatial patterns of asthma in Alameda County, California. *Prev. Chronic. Dis.* 3:A92
101. Rogers HS, Jeffery N, Kieszak S, Fritz P, Spliethoff H, et al. 2008. Mercury exposure in young children living in New York City. *J. Urban Health* 85:39–51
102. Rosenman KD. 2007. Are work-related conditions less common or were their definitions changed? *Occup. Environ. Med.* 64:429–30
103. Rosenman KD. 2009. Asthma, hypersensitivity pneumonitis and other respiratory diseases caused by metalworking fluids. *Curr. Opin. Allergy Clin. Immunol.* 9:97–102
104. Rosenman KD, Kalush A, Reilly MJ. 2007. Variations in worker compensation claims by company: the potential for achieving a significant reduction in claims. *Am. J. Ind. Med.* 50:415–20
105. Rosenman KD, Kalush A, Reilly MJ, Gardiner JC, Reeves M, Luo Z. 2006. How much work-related injury and illness is missed by the current national surveillance system? *J. Occup. Environ. Med.* 48:357–65
106. Rosenman KD, Reilly MJ, Henneberger PK. 2003. Estimating the total number of newly-recognized silicosis cases in the United States. *Am. J. Ind. Med.* 44:141–47
107. Ross Z, English PB, Scalf R, Gunier R, Smorodinsky S, et al. 2006. Nitrogen dioxide prediction in Southern California using land use regression modeling: potential for environmental health analyses. *J. Expo. Sci. Environ. Epidemiol.* 16:106–14
108. Ruser JW. 2008. *Examining evidence on whether BLS undercounts workplace injuries and illnesses*. **http://www.bls.gov/opub/mlr/2008/08/art2full.pdf**
109. Rubertone MV, Brundage JF. 2002. The Defense Medical Surveillance System and the Department of Defense serum repository: glimpses of the future of public health surveillance. *Am. J. Public Health* 92:1900–4

110. Ruckart PZ, Wattigney WA, Kaye WE. 2004. Risk factors for acute chemical releases with public health consequences: Hazardous Substances Emergency Events Surveillance in the U.S., 1996–2001. *Environ. Health* 3:10
111. Ruder AM, Waters MA, Butler MA, Carreon T, Calvert GM, et al. 2004. Gliomas and farm pesticide exposure in men: the upper midwest health study. *Arch. Environ. Health* 59:650–57
112. Rutstein DD, Mullan RJ, Frazier TM, Halperin WE, Melius JM, Sestito JP. 1983. Sentinel Health Events (occupational): a basis for physician recognition and public health surveillance. *Am. J. Public Health* 73:1054–62
113. Santelli J, Ginn E, Speers MA. 2000. An evaluation of human subjects protection at CDC/ATSDR. *IRB* 22:1–7
114. Schulte PA. 2005. Characterizing the burden of occupational injury and disease. *J. Occup. Environ. Med.* 47:607–22
115. Souza K, Davis L, Shire J. 2010. Occupational and environmental health surveillance. In *Occupational and Environmental Health: Recognizing and Preventing Disease and Injury*, ed. BS Levy, D Wegman, S Baron, R Sokas. Philadelphia, PA: Lippincott Williams & Wilkins. In press
116. Souza K, Steege AL, Baron SL. 2010. Surveillance of occupational health disparities: challenges and opportunities. *Am. J. Ind. Med.* 53:84–94
117. Stanbury M, Reilly MJ, Rosenman KD. 2003. Work-related amputations in Michigan, 1997. *Am. J. Ind. Med.* 44:359–67
118. Sutton PM, Mossman M, Reinisch F, Harrison RJ. 2002. A determination of healthcare worker exposure to *Mycobacterium tuberculosis* in two Californian hospitals. *J. Hosp. Infect.* 51:281–87
119. Talbott E. 2007. Can the concept of environmental public health tracking work in a real life setting? *J. Occup. Environ. Med.* 49:584–86
120. Teutsch SM. 2000. *Principles and Practices of Public Health Surveillance*. Oxford: Oxford Univ. Press
121. Thacker SB. 2000. Historical development. In *Principles and Practices of Public Health Surveillance*, ed. SM Teutsch, RE Churchill, pp. 1–16. Oxford: Oxford Univ. Press
122. Thacker SB, Berkelman RL. 1992. History of public health surveillance. In *Public Health Surveillance*, ed. WE Halperin, pp. 1–15. New York: Van Nostrand Reinhold
123. Thacker SB, Stroup DF. 1994. Future directions for comprehensive public health surveillance and health information systems in the United States. *Am. J. Epidemiol.* 140:383–97
124. Thacker SB, Stroup DF, Parrish RG, Anderson HA. 1996. Surveillance in environmental public health: issues, systems, and sources. *Am. J. Public Health* 86:633–38
125. Thurston GD, Bekkedal MY, Roberts EM, Ito K, Pope CA 3rd, et al. 2009. Use of health information in air pollution health research: past successes and emerging needs. *J. Expo. Sci. Environ. Epidemiol.* 19:45–58
126. US Census Bur. 2001. *Technical documentation: Census 2000 summary file 1*. **http://www.census.gov/prod/cen2000/doc/sf1.pdf**
127. Vaidyanathan A, Staley F, Shire J, Muthukumar S, Kennedy C, et al. 2009. Screening for lead poisoning: a geospatial approach to determine testing of children in at-risk neighborhoods. *J. Pediatr.* 154:409–14
128. Wang PC, Rempel DM, Hurwitz EL, Harrison RJ, Janowitz I, Ritz BR. 2009. Self-reported pain and physical signs for musculoskeletal disorders in the upper body region among Los Angeles garment workers. *Work* 34:79–87
129. Wartenberg D, Thompson WD, Fitzgerald EF, Gross HJ, Condon SK, et al. 2008. Developing integrated multistate environmental public health surveillance. *J. Public Health Manag. Pract.* 14:552–61
130. Wash. State Dep. Labor Ind. 2010. *About the SHARP program*. **http://www.lni.wa.gov/safety/research/about**
131. Wegman DH, Froines JR. 1985. Surveillance needs for occupational health. *Am. J. Public Health* 75:1259–61
132. Welch L. 1989. The role of occupational health clinics in surveillance of occupational disease. *Am. J. Public Health* 79(Suppl.):58–60
133. Xu X, Zborowski JV, Arena VC, Rager J, Talbott EO. 2008. Case-crossover analysis of air pollution and cardiorespiratory hospitalizations: using routinely collected health and environmental data for tracking: science and data. *J. Public Health Manag. Pract.* 14:569–76

134. Young LJ, Gotway CA. 2007. Linking spatial data from different sources: the effects of change of support. *Stoch. Environ. Res. Risk Assess.* 21(5):589–600
135. Zhu L, Carlin BP, Gelfand AE. 2003. Hierarchical regression with misaligned spatial data: relating ambient ozone and pediatric asthma ER visits in Atlanta. *Environmetrics* 14:537–57
136. Zierold KM, Anderson HA. 2006. Racial and ethnic disparities in work-related injuries among teenagers. *J. Adolesc. Health* 39:422–26
137. Zierold KM, Anderson HA. 2006. Severe injury and the need for improved safety training among working teens. *Am. J. Health Behav.* 30:525–32
138. Zuckerman N, Szeinuk J. 2006. ACOEM evidenced-based statement: medical surveillance of workers exposed to crystalline silica—some comments and suggestions. *J. Occup. Environ. Med.* 48:659–60

Annual Review of Public Health

Volume 32, 2011

Contents

Symposium: Determinants of Changes in Cardiovascular Disease

Epidemiology and Biostatistics

Cardiovascular Disease: Rise, Fall, and Future Prospects
Russell V. Luepker 1

Proportion of the Decline in Cardiovascular Mortality Disease due to Prevention Versus Treatment: Public Health Versus Clinical Care
Earl S. Ford and Simon Capewell 5

Social Determinants and the Decline of Cardiovascular Diseases: Understanding the Links
Sam Harper, John Lynch, and George Davey Smith 39

Sodium Intake and Cardiovascular Disease
Alanna C. Morrison and Roberta B. Ness 71

Environmental and Occupational Health

Public Health Practice

Social Environment and Behavior

Health Services

Indexes

Errata

An online log of corrections to *Annual Review of Public Health* articles may be found at http://publhealth.annualreviews.org/