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Climate Change and Public Health Surveillance: Toward a Comprehensive Strategy

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Abstract

Context—Climate change poses a host of serious threats to human health that robust public health surveillance systems can help address. It is unknown, however, whether existing surveillance systems in the United States have adequate capacity to serve that role, nor what actions may be needed to develop adequate capacity.

Objective—Our goals were to review efforts to assess and strengthen the capacity of public health surveillance systems to support health-related adaptation to climate change in the United States and to determine whether additional efforts are warranted.

Methods—Building on frameworks issued by the Intergovernmental Panel on Climate Change and the Centers for Disease Control and Prevention, we specified 4 core components of public health surveillance capacity relevant to climate change health threats. Using standard methods, we next identified and analyzed multiple assessments of the existing, relevant capacity of public health surveillance systems as well as attempts to improve that capacity. We also received information from selected national public health associations.

Findings—Multiple federal, state, and local public health agencies, professional associations, and researchers have made valuable, initial efforts to assess and strengthen surveillance capacity. These efforts, however, have been made by entities working independently and without the benefit of a shared conceptual framework or strategy. Their principal focus has been on identifying suitable indicators and data sources largely to the exclusion of other core components of surveillance capacity.

Conclusions—A more comprehensive and strategic approach is needed to build the public health surveillance capacity required to protect the health of Americans in a world of rapidly evolving climate change. Public health practitioners and policy makers at all levels can use the findings and issues reviewed in this article as they lead design and execution of a coordinated, multisector strategic plan to create and sustain that capacity.

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Keywords

climate change; public health policy; surveillance

Introduction

Climate change poses an extraordinarily broad range of threats to human health.[1] The Intergovernmental Panel on Climate Change (IPCC) identifies direct effects "due to extreme heat events, floods, and other extreme weather events"; indirect effects "from environmental and ecosystem changes, such as shifts in patterns of disease-carrying mosquitoes and ticks, or increases in waterborne diseases due to warmer conditions and increased precipitation and runoff"; and indirect effects "mediated through societal systems such as undernutrition and mental illness from altered agricultural production and food insecurity, stress, and violent conflict caused by population displacement; economic losses due to widespread 'heat exhaustion' impacts on the workforce; or other environmental stressors, and damage to health care systems by extreme weather events."[2]

To date, the burgeoning scientific literature on public health and climate change has focused mainly on understanding the health consequences of climate change and exploring the types of interventions that could be pursued to minimize those impacts. Greater attention needs to be given to the functional capacity of public health agencies to shape and effect those interventions. This article focuses on their capacity to design and conduct climate change-related surveillance.

Public health surveillance has been defined as "the systematic, ongoing collection, management, analysis, and interpretation of data followed by the dissemination of these data … to stimulate public health action."[3] The IPCC and the US Global Change Research Program recognize explicitly that the health impacts of climate change are mediated by the capacities of the public health sector, including surveillance systems.[4]

Many calls have been issued for the development of adequate capacity by US public health agencies to conduct climate change-related public health surveillance.[5,6] This article reports on a review of activities undertaken to assess and improve the relevant surveillance capacity of state, local, and federal public health agencies. It further outlines steps the public health community can consider taking to ensure adequate surveillance capacity.

Methods

We conducted literature searches for attempts to define a conceptual framework or model for climate change-related public health surveillance and, following Hall et al,[7] for activities focused on 4 core components of public health surveillance capacity: indicators and data; electronic and other systems and tools to collect and analyze data; a professional workforce competent in relevant skills; and supportive financial and other policies.

The reviews, conducted during March–July 2015 and again in December 2015, were based on searches in the English-language biomedical literature, gray literature, and other

publications of health-oriented organizations, including searches of the PubMed, Public Library of Science, Social Science Research Network, Google Scholar, and CQ.com (for pertinent federal and state legislation) databases using combinations of the terms “public health,” “public health surveillance,” “surveillance capacity,” and “public health monitoring” with the terms “climate” and “climate change,” with no time parameters. Searches were conducted also of the Web sites of selected federal agencies, the Association of State and Territorial Health Officials (ASTHO), Council of State and Territorial Epidemiologists (CSTE), the National Association of County & City Health Officials (NACCHO), and the Association of Public Health Laboratories, all state public health departments, selected county and city health departments, 25 US nongovernmental organizations and philanthropic organizations, the IPCC, and the World Health Organization.

Findings

Our searches located no references to conceptual models or frameworks for climate change-related public health surveillance.

Assessments of existing public health surveillance capacity

We located 5 reports that assessed 1 or more components of climate change-related public health surveillance capacity nationally:

- Authors of a 2009 CSTE study highlighted 2 gaps in data sources that they considered serious: the lack of a national surveillance data set to analyze hyperthermia impacts on morbidity for all populations and of a surveillance database for deaths and injuries related to weather events.[8]
- In 2008 and 2012 NACCHO polls of local health department preparedness for climate change, three-quarters of the respondents reported that their agencies “lacked the expertise to assess the potential impacts” of climate change.[9]
- Between 67% and 87% of respondents to 2009 and 2012 ASTHO surveys reported “adequate surveillance capacity” for food-borne, vector-borne, and waterborne diseases related to climate change; 51% wanted additional “tools” (not further defined) for surveillance and related purposes; and 67% called for more staff training.[10]

Several reports assessed elements of climate change-related surveillance in individual states. Beginning in 2010, the Climate and Health Program of the Centers for Disease Control and Prevention (CDC) has provided financial and technical assistance to 18 state and local public health agencies to support adaptation to climate change.[11] As of early 2015, most grantees had conducted some form of surveillance assessment. For example, an assessment of Massachusetts boards of health found that more than 80% wanted greater access to surveillance data.[12] A 2007–2008 survey of local California health departments found that most conducted surveillance for vector-borne illnesses but that fewer than half tracked heat-related morbidity and mortality.[13]

Federal government agencies appear not to have formally assessed their capacity to conduct climate change-related public health surveillance. Centers for Disease Control and Prevention, however, concluded in 2014 that enhanced climate-related surveillance would support adaptation for climate change-related global health; respiratory health; vector-, food-, and waterborne diseases; sexually transmitted infections; and mental health.[14]

Finally, our searches located no assessments of existing policies related to public health surveillance and climate change.

Efforts to strengthen public health surveillance capacity

The CSTE, NACCHO, and ASTHO have taken steps toward strengthening state and local health departments' preparedness for climate change, in some cases with CDC support.

- Beginning in 2004, CSTE convened state epidemiologists to create public health indicators for climate change. Following pilot tests, CSTE recommended in 2012 that state and territorial health departments include 24 indicators, belonging to 5 domains, in their climate change-related surveillance.[15]
- In 2007, NACCHO recommended that local health departments "enhance surveillance of climate-sensitive diseases"[16] and in 2014 recommended developing indicators for local public health climate change surveillance.[9] The organization also recommended that local health departments monitor the health impacts climate change has on local communities on an ongoing basis.[17]
- A 2014 ASTHO tool kit recommended that health departments assess their existing surveillance programs and recommended monitoring 24 indicators in 7 domains.[18] Regarding the workforce, by 2013, 6 state and local public health professionals had participated in the ASTHO-sponsored Environmental Public Health Tracking Peer-to-Peer Fellowship Program's advanced training and experiential learning in tracking related to climate change.[19]

As of late 2015, ASTHO advised that 1 state and 1 US territory had started using the ASTHO tool kit (J. Blumenstock, e-mail communication, 2015), CSTE had not received information on health department implementation of its recommended indicators (J. Wurster, e-mail communication, 2015), and NACCHO had not received feedback on local health department use of relevant resources (J. Li, e-mail communication, 2015). These reports suggest little action to implement the recommendations of the 3 organizations.

At least 2 attempts have been made to evaluate various existing and proposed indicators using such criteria as sensitivity, specificity, data availability, quality, temporality, and comparability over time and place.[8,20] Centers for Disease Control and Prevention Climate and Health Program grantees have worked to strengthen their capacity to conduct climate change-related surveillance by developing new indicators and using existing indicators in novel ways. The Climate and Health Syndromic Surveillance Workgroup (with state health department, CDC, CSTE, and Canadian partners) works to improve ongoing syndromic surveillance activities that might inform development of syndromic surveillance for climate-related environmental exposures.[21] In 2015, the group surveyed US and Canadian public health agencies on their use of syndromic surveillance systems to detect and reduce illnesses

related to extreme weather events and climate change. Initial results indicated that 80% of respondents found those systems valuable.

Several additional state and local health departments have taken steps toward strengthening surveillance capacity, among others, the Michigan, Minnesota, and New Hampshire state health departments, San Francisco City, and the Los Angeles County public health department.

The accompanying table presents selected indicators for public health surveillance related to climate change that have been proposed by public health agencies, private entities, and researchers (Table).

Summary of findings

A number of efforts have been made to assess existing public health surveillance capacity in the United States and to encourage development of new capacity. (We located no activities specific to tribes or US territories.) Yet, while important, these efforts as a whole remain embryonic.

- Indicators and data: While more than 80 indicators have been suggested by multiple public and private entities (making indicators the most actively addressed surveillance component), many overlap, lack common scope and definitions, and come from organizations working in apparent isolation from each other.
- Systems: Attempts do not appear to have been made to assess or develop pertinent electronic and other systems. Nor do the functional requirements for such systems appear to have been specified, a critical first step in developing them. Several organizations have developed pertinent analytic tools, but these efforts focus on a small number of specific health-climate relationships and appear to be exploratory in nature.
- Workforce: Limited efforts appear to have been made to strengthen the relevant skills of the public health workforce.
- Policies: Pertinent federal and state legislation or regulations do not appear to have been enacted. One bill has been introduced repeatedly in Congress (but not passed) to require development of a federal climate change adaptation strategic plan, including climate change-related public health surveillance.[32] A similar Hawaii bill did not pass; instead, the legislature authorized a study committee to develop a plan that would include enhanced disease surveillance systems.[33]

These characterizations may be qualified by limitations in our search methods, which might have excluded some relevant sources, for example, unpublished proceedings of meetings convened by organizations other than those we included.

Discussion

Our findings suggest that a more comprehensive and strategic approach is needed to overcome the substantial challenges to development of surveillance capacity to address climate change-related health impacts.

Perhaps the greatest challenge is the expansive scope involved. An adequate surveillance system will need to capture data on many different types of climate change health impacts, some as yet perhaps unknown; generate data on many different populations and spatial levels[34]; address surveillance needs that change over time (eg, regions at lower latitudes may need to monitor mosquito-borne diseases before others do); and serve the information needs of public health agencies at different levels and of diverse partner organizations, policy makers, and researchers.

Technical complexity is another challenge. Currently available data and analytic methods may not support determination of relationships between exposure to climate change-related risk factors and their health consequences.[35] Heat waves, for example, can be brief, making it difficult to assess their impacts on slow-developing health problems such as cardiovascular and renal disease, a problem of temporality. Detection of heat-related morbidity may be difficult in small jurisdictions where case counts are low, a problem of scale. Extreme precipitation events may affect small areas while many weather stations report precipitation data only for larger regions.

Valuable assets, however, exist to help meet such challenges. Among these is the rich experience of public health practitioners in designing surveillance systems. Once focused mainly on infectious disease outbreaks, surveillance today also addresses noncommunicable diseases, genetic conditions, injury, risk factors, health services, implementation of interventions, and adoption of health-related policies, among other subjects. Public health surveillance practitioners engage with partners in health care and other sectors, for example, through the National Syndromic Surveillance Program. Newly developed, relevant technical resources include the data portal managed by the CDC National Environmental Public Health Tracking Network (part of the Public Health Tracking Program), a publicly available, online tool that includes county-level data relevant to climate and health.

Approach toward ensuring adequate surveillance capacity

A foundational step toward building adequate public health surveillance capacity for climate change-related purposes would be to systematically identify end user needs for surveillance-based information. A useful preliminary step would be to outline likely end users and their likely information needs.

The many indicators that have been proposed can serve as an approximation of the types of climate change-related surveillance information end users may need. At present, public health programs are the principal end users. But the number and diversity of end users are likely to expand as recognition grows of the extensive health consequences of climate change. Additional end users soon may include housing and urban planning agencies seeking information about trends in heat stress, mosquito- and waterborne disease, and

flood-related injury to frame new standards for housing and city design; environmental protection agencies needing information to identify drinking water supplies at risk of contamination; and employers and occupational safety agencies wanting information to identify and protect out-of-doors workers at risk of heat exhaustion and skin cancer.

Another class of likely end users is the National Oceanic and Atmospheric Administration, the US Global Change Research Program and IPCC themselves, and other entities that need information from public health surveillance to model climate change impacts, track health-related trends, and set research priorities.

Conceptually, once user information needs are known, steps could be taken to assess the adequacy of existing surveillance capacity to fulfill those needs; identify any gaps in that capacity; and formulate and implement plans to fill those gaps. Much practical work would be required to translate this simplified conceptual agenda into robust, actual surveillance capacity. The following section highlights some of the developmental and implementation issues and priorities that public health professionals can anticipate encountering in conducting this work.

Indicators and data

Distillation of a consensus set of core indicators—pertinent to widely shared health concerns—could encourage public health agencies at all levels to initiate climate change-related surveillance activities. Public health agencies that serve vulnerable populations or that are affected disproportionately by other climate change health threats could select, individually or in concert, additional indicators relevant to those priorities. Large, well-resourced public health agencies might take the lead in both these areas, generating data sets and experience ultimately of value to all.

Many public health agencies already have access to sources of data that likely would be relevant to a core set of indicators, such as notifiable disease surveillance programs, environmental health programs, and syndromic surveillance partnerships with hospitals and other health care providers.

Over time, climate change-related surveillance is likely to require an expanding spectrum of data. The observation that “Public health may be affected by … the [climate change] adaptation and mitigation strategies implemented by various sectors (e.g., housing, transportation, agriculture, etc.)” suggests how complex such sources of data may become.[36]

The characteristics of the data that end users need have important implications for surveillance and for the information systems core component, in particular. Data that users require in real time, in high volume, and from multiple sources or jurisdictions presume sophisticated electronic reporting systems and automated analytic capacity. This would characterize data on daily morbidity and mortality during an extended heat wave affecting a multistate region. In contrast, some users may want data to monitor long-term trends in population heat vulnerability and on steps cities take to reduce heat island effects and to protect elderly and low-income residents; surveillance capacity in this case might comprise periodic surveys and questionnaires, with results recorded in stand-alone data sheets.

Information systems

A guiding principle for the development of the information systems component of climate change-related surveillance capacity almost certainly will be to maximize use of existing capacity: electronic and other data collection systems, analytic tools, and information exchange pathways. Building on such existing programs as the National Notifiable Diseases Surveillance System, the National Syndromic Surveillance Program, disease registries, and established health surveys could help minimize the need for additional resources and the complications that duplication of existing surveillance systems could cause. Centers for Disease Control and Prevention adopted this principle in its 2014 policy to minimize creation of new electronic surveillance systems beyond the 150 systems CDC then operated.[37]

A practical step in applying this principle would be to identify any critically needed surveillance information that existing systems cannot generate and to prioritize filling any such gaps. It is possible that existing electronic and nonelectronic systems, in current or modified form, could provide much or all of the needed capacity. Existing syndromic surveillance systems might become a source of data for surveillance of heat-related illnesses. Syndromic surveillance may have still broader value outside of the emergent health context by capturing data on inhalation of pollen and particulates and on heat exposure.

In a different vein, field experimentation suggests that relatively inexpensive sentinel surveillance, based on reporting by the lay public, can generate valuable information about the impacts climate change has on respiratory health, food poisoning, cold-related injuries and fatalities, and food and water security at the community level.[38]

Another class of potentially valuable data currently is not collected through existing conventional or syndromic surveillance systems. For example, National Weather Service data on environmental heat conditions are directly relevant to climate change–related health dangers and potentially could be used in surveillance. Public health agencies may explore accessing data from other unconventional sources as well.

Workforce

A series of reports have recommended core competencies for the general public health workforce. A similar effort may be warranted for competencies specific to climate change-related surveillance. Reports cited previously indicate that state and local public health practitioners perceive a need for training and expertise in climate change-related surveillance. Another survey found “considerable” gaps in public health workforce proficiencies in syndromic surveillance.[39]

A broad spectrum of competencies is likely to be needed, for example, in technical operation of surveillance systems, integration of data from diverse and unconventional sources, data analysis and interpretation, communication of findings to public health decision makers, and formation of surveillance-oriented collaborations among partners in multiple sectors.

Delivery of training to the existing public health workforce could build on such assets as the CSTE Applied Epidemiology Program, the ASTHO Environmental Public Health Tracking

Peer-to-Peer Fellowship Program, and the CDC Epidemic Intelligence Service, among other existing training programs. Schools of public health could consider contributing both to training the current workforce and to the development of competencies in the next-generation workforce.

Policies

Like all government public health activities, surveillance is conducted within an environment of policies. These policies take the form of statutes enacted by legislative bodies, executive-branch regulations, codified administrative practices, and interagency and interjurisdictional memoranda of agreement, among others.

State and local public health agencies that commit to strengthening their climate change-related surveillance capacity may wish to explore whether adoption of certain policies could help that effort. Substantively, such policies variously can authorize or mandate agencies to take defined actions, circumscribe specified actions (eg, infringement on privacy), and provide funding and other resources.

Different jurisdictions likely will reach different conclusions, reflecting their existing policy environments and the scale and complexity of the capacity they wish to develop. Some may find it helpful to review the provisions of HR 1275 and the report of the legislatively authorized Hawaii working group that called for increasing public health surveillance specifically to detect and track climate change-related disease.[40]

Conclusion

Projected climate change impacts on health suggest that development and execution of a comprehensive strategy to ensure adequate public health surveillance capacity should begin soon. It is probable that such capacity, once established, will comprise multiple surveillance systems—a “system of systems”—given the heterogeneity in end user information needs across multiple sectors and in the types of data, data sources, electronic systems, and analytic tools required to meet those needs. For example, integration of data across different indicator domains may not always be suitable for automation. In some cases, effective integration may be achieved more readily by analysts as they probe and interpret relationships between qualitatively different data sets.

The initial efforts undertaken to assess and strengthen elements of capacity are helpful steps toward formulation of such a strategy. Those who design and implement the strategy can take advantage of other valuable resources as well. Perhaps most important among those are the existing public health surveillance capacity of state, local, and federal agencies and the rich body of experience gained through its development and through operation of ongoing surveillance activities that capacity enables.

Undertaking development of a comprehensive approach would involve the engagement of partners in many sectors. Clearly, the public health sector can contribute the driving thrust and continuing leadership. Development of a collaborative strategic plan would have many stages. An early goal would be to formulate a consensus conceptual framework to help guide

design of comprehensive plans for strengthening capacity and setting priorities and objectives. A practical framework for organizing design and execution of the strategy would helpfully focus on issues and priorities related to the core components of climate change-related public health surveillance capacity.

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Implications for Policy & Practice

- Public health practitioners are uniquely positioned to lead efforts to protect Americans from the grave health threats that climate change poses.
- To fulfill this role, however, they need robust and dynamic surveillance, among other key resources.
- This article provides findings and recommendations that public health practitioners and policy makers at all levels can use in designing and executing a comprehensive strategic plan to create capacity to support and sustain those surveillance systems and programs in the face of heterogeneous and rapidly evolving climate change health threats.

TABLE

Selected Indicators Proposed for Public Health Surveillance Related to Climate Change

Indicator	Source of Proposed Indicator
A. Environmental domain	
1. Heat	
Maximum, minimum, and diurnal temperature	CSTE[15]
Heating and cooling degree days	EPA[22]; USGCRP[23]
Future projections of extreme heat	CDC[24]
Historical extreme heat days and events	CDC[24]
Frequency of extreme heat events	Upperman et al[25]
Ambient air temperature	ASTHO[26]
2. GHG	
CO_2-equivalent GHG emissions per capita, by sector, eg, transportation and agriculture	CSTE[15]
3. Air quality	
Air mass stagnation events	CSTE[15]; NRC[27]
Pollen count	ASTHO[26]; CSTE[15]
Change in length of ragweed pollen season	EPA[22]
Number of wildfires and percentage of total acres impacted by state	CSTE[15]
Frequency, severity, distribution, and duration of wildfires	NRC7
4. Water safety	
Water temperature and turbidity	ASTHO[26]
Rainfall from heavy precipitation events	ASTHO[26]
5. Drought	
Drought events	ASTHO[26]
6. Disease vectors	
Positive test results in mosquito sentinels and reservoirs	CSTE[15]
Spatial distribution of vectors/sentinel species for emerging vector-borne diseases	ASTHO[26]
7. Food supply	
Length of growing season	EPA[22]
8. Land use	
Deforestation and other land use trends	NRC[27]
B. Vulnerability domain	
1. Demographic characteristics	
General community vulnerability to climate-related events	ASTHO[26]

Indicator	Source of Proposed Indicator
People older than 65 y and younger than 5 y, with chronic and mental diseases, incapacities, who live alone, have low incomes, live in urban heat islands, lack access to a public pool within 1 km, lack public transit access to a beach, or lack access to a park or green area within 500 m	Bernier et al[28]
Percentage of population 5 y old and older with a disability	CDC[24]
Percentage of population ever diagnosed with diabetes	Manangan et al[29]
Age-adjusted estimates of percentage of adults 20 y of age or older with diagnosed diabetes	CDC[24]
Rate of hospitalization for heart disease among Medicare beneficiaries over a 7-y period	CDC[24]
Age-adjusted rate of hospitalization for heart attack among persons aged 35 y and older per 10 000 population	CDC[24]
Access to cooling centers	CSTE[15]
Population density	CDC[24]
Percent population of a race other than white	CDC[24]
Percent or number of population below the poverty line	Manangan et al[29]
Median household income	CDC[24]
Percent population 65 y of age or older and living alone	CDC[24]
Location and vulnerability of populations at highest health risk following extreme weather events	ASTHO[26]; NRC[27]
Location of, and number of children and others served by day care centers, schools, and health care centers; proportion of those facilities that are air conditioned	Bernier et al[28]
Populations living at low elevations	Frumkin et al[30]
Percentage of people without health insurance	CDC[24]
2. Vulnerability of locations and resources	
Per capita availability of health care facilities, professionals, supplies, equipment	NRC[27]
Hospital counts	CDC[24]
Hospitals per 100 000 people	CDC[24]
Urban areas, school day care centers, and health centers sensitive to heat waves and extreme weather events	Bernier et al[28]
Local/regional food production locations and volume	ASTHO[26]
Capacity to store and deliver food during and after extreme weather events	ASTHO[26]
Energy and water efficiency of facilities and equipment in food service establishments	ASTHO[26]
Percentage of census tract area not covered in vegetation	Manangan et al[29]
Percentage of forest cover	CDC[24]
Percentage of cultivated crop land use	CDC[24]
Percentage of developed land use	CDC[24]
3. Exposure to risk factors	
Location of chemical facilities at risk of extreme weather events	ASTHO[26]
Rates of agricultural chemical application	ASTHO[26]
Exposure to injury from transportation used during and after extreme weather events	ASTHO[26]
C. Health domain	
1. Heat-related	
Heat-related death rate	EPA[22]

Indicator	Source of Proposed Indicator
Rate of deaths, hospitalizations, and ED visits during summer months	CSTE[15]
Number and rate of heat stress ED visits and hospitalizations	CDC[24]
Excess daily all-cause mortality due to heat	Cheng and Berry[20]
2. Utilization of health care services	
ED and ambulatory care visits, hospital admission, mortality, mental health outcomes	Frumkin et al[30]
3. Morbidity and mortality	
Daily nonaccidental mortality	Cheng and Berry[20]
Preventable deaths from climate change	Cheng and Berry[20]
DALYs lost from climate change	Cheng and Berry[20]; NRC[27]
Injuries and deaths due to extreme weather events	ASTHO[26]; CSTE[15]
Cancer rates for respiratory disease	NRC[27]
Food-borne, waterborne, and vector-borne diseases	Multiple
Annual incidence of confirmed *Vibrio* infections	USGCRP[23]
Incidence of Lyme disease cases in humans	Cheng and Berry[20]; CSTE[15]; FPA[22]
Incidence of West Nile virus cases in humans	Cheng and Berry[20]; CSTE[15]
Human cases of valley and dengue fever and of hantavirus	CSTE[15]
Allergic disease related to climate change	CSTE[15]
Morbidity and mortality rates of populations exposed to toxic chemicals during extreme weather events	ASTHO[26]
Premature deaths due to air pollution, eg, ozone and PM 2.5	Cheng and Berry[20]
Population movement and migration	Frumkin et al[30]; NRC[27]
D. Climate change mitigation domain	
1. Energy-related	
Total energy consumption per capita	CSTE[15]
Renewable energy consumption per capita	CSTE[15]
Vehicle miles traveled	CSTE[15]
2. Extreme weather-related	
Storm surge capacity in coastal areas	ASTHO[26]
E. Climate change adaptation domain	
1. Plans	
Development of state climate change adaptation plans	CSTE[15]
Development of local climate change adaptation plans	City of San Francisco[31]
Adoption of urban planning and design policies to reduce heat exposure	Manangan et al[29]
Heat island mitigation plans	CSTE[15]

Indicator	Source of Proposed Indicator
2. Public health agency actions	
Health surveillance systems related to climate change	CSTE[15]
Public health workforce trained in climate change research, surveillance, and adaptation	CSTE[15]; NRC[27]
3. Population characteristics	
Access to cooling centers	ASTHO[26]; CSTE[15]
Levels of exercise and fitness, eg, rates of bicycle, public transport, and car usage	NRC[27]
F. Policy	
1. State and local government actions	
Formation of state climate change advisory board	CSTE[15]
Formation of local climate change advisory board	City of San Francisco[31]
Development of state climate change action plan	CSTE[15]; NRC[27]
Completion of state or local greenhouse gas inventory	CSTE[15]
Number and percentage of local governments participating in ICLEI-Local Governments for Sustainability (ICLEI)	CSTE[15]
Percentage of population living in cities participating in the U.S. Conference of Mayors Climate Protection Agreement	CSTE[15]

Abbreviations: ASTHO, Association of State and Territorial Health Officials; CDC, Centers for Disease Control and Prevention; CSTE, Council of State and Territorial Health Officials; DALYs, disability-adjusted life years lost; ED, emergency department; EPA, Environmental Protection Agency; GHG, greenhouse gasses; ICLEI, International Council for Local Environmental Initiatives; NRC, National Research Council; PM, particulate matter; USGCRP, U.S. Global Change Research Program.