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Climate Change and Public Health

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LETTER FROM THE EDITOR

Climate change. There is scientific consensus that our planet is in danger because of fossil fuel emissions. There is also scientific agreement that we can—and we must—take actions to adapt to climate-related changes and to mitigate the risks of future changes. Because the details of climate change are so complex and, in some cases, imprecise and still evolving, it is sometimes hard to see the big picture: our Earth is in trouble. The actions required of individuals, businesses, communities, and nations are immense. Despite the science, the complexity of climate change and the undeniable sacrifices and actions we must take to survive, contribute to confusion—even denial—about the immediacy and gravity of the threats and the opportunities. We developed this volume to assert that climate change is the most compelling public health challenge of our time. I thank our guest authors, all of whom shared their knowledge and their innovative work. I am especially grateful to Kristin Raab, an effortless writer and keen thinker, who was continuously available for guidance and help with this volume. Bill Toscano, always a generous colleague, not only authored a great article, but he also shared many references and ideas with me that strengthened this volume. Carrie Vogelsang offered her encouragement and introduced me to two fine public health professionals (Colleen Moran and Elena Grossman) who made wonderful contributions. My colleague, Sara Benning, was (as always) a sharp editor, who gave this project the full measure of her considerable organizational and creative skills. Julie Longo is simply an artist: she made this volume look good. And Tory Bruch never hesitated to respond to requests with grace and skill. This volume thus represents the ideas, the passions, and the creativity of many fine people. I hope their efforts inspire, educate, and stimulate you to expand your knowledge about climate change and to make a commitment to make the individual changes—and support the policies—that will allow our Earth to survive and thrive.

—Wendy L. Hellerstedt, MPH, PhD

Note: Many of the sources we cited in this volume are federal sources. As we go to press (May 2017), we are aware that some US government websites will delete or modify information on climate change.

The Center for Leadership Education in Maternal and Child Public Health is committed to improving the health of infants, children, women and families. Center faculty and staff offer a Master's degree in Public Health (including an online degree program), continuing professional education, and consultation and technical assistance to community-based organizations and agencies. Center faculty are involved in intervention and etiologic research in child health, adolescent health, family health, health disparities, reproductive health, and women's health. See our website at epi.umn.edu/mch and our Facebook page at https://facebook.com/MCHUMN, or follow us on Twitter (https://twitter.com/umn_mch).

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A public health response involves both primary and secondary prevention.

Climate Change is Happening and It Demands a Public Health Response

by Wendy L. Hellerstedt, MPH, PhD

Among scientists, there is agreement about climate change:[1-4] human activity has led to increasing greenhouse gases (especially carbon dioxide) and a warming planet. A warming planet has negative consequences in terms of environmental degradation, extreme weather events, and social disruption—all of which have health and economic consequences. Climate change requires global and local actions to mitigate further damage and allow people and other species to adapt. The following provides a brief overview of climate change and public health responses.

Global Temperatures Are Rising at Unprecedented Levels

It is believed that a temperature increase of 2°C above the pre-Industrial Period level could have catastrophic effects on sea levels, food production, biodiversity, and water supplies.[3] We are already halfway to that "catastrophic" mark: 2016 was the hottest year since measurement began in 1880 and the third year in a row to set a record for average global temperature.[5] Since 1880, global temperatures have risen by more than 1˚C (1.8˚F), while levels of carbon dioxide in the atmosphere have increased from 280 parts per million (ppm) to more than 400 ppm.[5] Without intervention, the global mean surface temperature is projected to rise between 3.7–4.8°C over the 21st Century.[3]

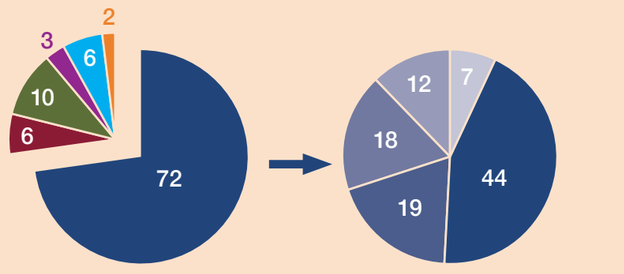
Greenhouse Gases, Especially Carbon Dioxide, Are Main Contributors to Climate Change

The primary influence on climate change is carbon dioxide (CO_2). CO_2 concentrations on earth started to rise 100-150 years ago when people started burning more fossil fuels. For millennia before the Industrial Period, CO_2 was stable at about 280 ppm. In 2013 the global concentration of CO_2 in the atmosphere reached 400 ppm for the first time in recorded history.[5] It is thought that CO_2 should be limited to 350 ppm to prevent "dangerous" climate change.[3]

Are there factors other than carbon dioxide that influence climate change? Absolutely—and some of those factors are natural (e.g., the tilt of the sun, natural changes in CO_2, other greenhouse gases

that trap heat and keep the earth warm). But the scientific evidence overwhelmingly shows that human-generated greenhouse gases are the major force driving climate change, far outweighing the effects of any natural factors. Many studies show that the combined effects of all possible natural drivers of climate could not explain the temperature increase over the last half century.[4] Further, the problem of human-generated greenhouse gases is becoming worse: emissions between 2000 and 2010 were larger than in the previous 30 years.[3] And half of all of the human-made CO_2 emissions between 1750 and 2010 occurred in the last 40 years.[3]

Estimated Percent Distribution of All Global Greenhouse Gas Emissions, 2013



Source of data: Climate Analysis Indicators Tool: WRI's Climate Data Explorer [Internet]. Washington, DC: World Resources Institute; 2015. Available from: http://cait.wri.org

Human Activity is the Main Cause of Climate Change

Scientists have determined that it is extremely likely that the increase in greenhouse gas emissions from human activity has caused more than half of the observed increases in temperature over the last 60 years, making it the largest driver of climate change.[3] The pattern we have observed, in which warming has occurred in the lower portions of the atmosphere (the troposphere) and cooling has occurred at higher levels (the stratosphere), is consistent with how greenhouse gases operate. Although natural forces affect the climate (e.g., volcanoes, variations in the sun's energy), they do not account for the warming that has occurred.[3] When models only include these natural drivers of climate change, they cannot reproduce the recent increase in temperature. Only when they include the increase in greenhouse gas emissions due to human activities can they replicate the observed changes.[6]

Other evidence that human activity is causing climate change include:[7]

- Ice cores from Greenland and Antarctica show that CO_2 and other greenhouse gas concentrations were relatively stable for thousands of years, but began to rise about 200 years ago, when humans began to engage in large-scale agriculture and industry. Concentrations of these gases are now higher than at any time for which we have ice core evidence, which stretch back 800,000 years.[3]
- Some greenhouse gases, such as industrial halocarbons, are only made by humans. Their accumulation in the atmosphere can only be explained by human activity.[7]
- Carbon comes in different isotopes. CO_2 from fossil fuels has a certain isotopic "signature" that differs from other sources of CO_2. Scientists measure the different isotopes and have confirmed that the increase in atmospheric CO_2 is predominantly from fossil fuel combustion.[7]

The International Panel on Climate Change summarized human impact in its 2013 report:

> *It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century… It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forces together.*[3]

As Global Temperatures Rise, Extreme Weather Events—and Other Consequences—Are Becoming More Frequent and Severe

Globally, the number of weather-related natural disasters has more than tripled since the 1960s.[8] Climate change is a major contributor to environmental disasters, like drought, floods, landslides, wildfires, and storms.[1,4,8-10] It disrupts habitats, causing loss of biodiversity, and contributes to desertification, ocean acidification, and sea level rise.[1]

Warmer temperatures can increase the risks of heat-related illness and even death.[1,8,10,11] Warmer temperatures can also help expand the ranges of diseases carried by insects or ticks, bringing them to regions where they were previously not a threat.[11] Warmer temperatures can increase smog, reducing air quality and causing health issues for the young, elderly, or those with respiratory problems.[1,8,10,11] Climate change is also associated with many social determinants of health, including food and water availability and secure and stable shelter.[4,10] The impact on these resources can trigger or exacerbate migration, conflict, and political instability. For example, heat stress may be the reason for the recent migration of farmers in Pakistan[12] and the droughts in Syria may be responsible for the migration of perhaps one million farmers to urban settings.[13] An equally important issue is that people may be trapped in unstable or challenging environments by climate change because of poverty, age, sex, ill health, or inability to move.[1,8,10]

Scientists agree that if humans continue to burn fossil fuels, cut down forests, build and maintain high-carbon and inefficient buildings, and engage in other activities that release greenhouse gases into the atmosphere, we may reach a tipping point and may not be able to sustain life.[1-4,10,11,14] Among the near-future concerns:

What We Know

The American Association for the Advancement of Science (AAAS) has a *What We Know* Initiative to help people understand that climate change is happening and that its risks are real. Among the resources on its website (http://whatweknow.aaas.org) is a short report (in English and Spanish) that simply details the "reality, risks, and response to climate change." Its three key messages are:

Reality: About 97% of climate scientists have concluded that human-caused climate change is happening. "This agreement is documented not just by a single study, but by a converging stream of evidence over the past two decades from surveys of scientists, content analyses of peer-reviewed studies, and public statements issued by virtually every membership organization of experts in this field." Climate change is responsible for the sea-level rising and extreme events, like heat waves.

Risks: "We are at risk of pushing our climate system toward abrupt, unpredictable, and potentially irreversible changes with highly damaging impacts. Earth's climate is on a path to warm beyond the range of what has been experienced over the past millions of years."

Response: "The sooner we act, the lower the risk and cost…The CO_2 we produce accumulates in Earth's atmosphere for decades, centuries, and longer." The AAAS report notes that we have responded to other major environmental challenges (e.g., acid rain) with greater benefits than costs and thus we may be able to manage climate change, too, if we act with soon and responsibly.

- There will be more frequent hot—and fewer cold—extremes in temperature in most regions of the world. Heat waves will thus continue to occur with higher frequency and last longer;[1]
- More species will be endangered (e.g., most recently the bumblebee was put on the endangered species list);
- Areas of the world—including the western US and Spain—will become drier and perhaps desert-like;[14]
- The ocean is becoming very acidic quickly, making it unclear whether ocean life will adapt (e.g., baby oysters and shellfish are having difficulty developing) and;[14]
- Livestock, fish production, and crop yields will decline because of altered rainfall, extreme weather, and increased pests.[14]

A Time for Action: Public Health Responses

Climate change is a relatively new and unique public health stressor, but many of its consequences (e.g., illness related to extreme heat, vector-borne diseases) are familiar to public health professionals. A public health response involves both primary and secondary prevention.

Primary prevention, *mitigation*, will involve policy, technology, and other actions to slow, stabilize, or reverse climate change by reducing the greenhouse gas emissions responsible (e.g., using clean energy, developing carbon capture and storage technologies, changing behaviors).[15] Many of these measures will occur outside of traditional public health.

Secondary prevention, *resilience* and *adaptation*, will involve programs and policies to help businesses and communities withstand changes that cannot be avoided.

Public health strategies or approaches will include those associated with public health preparedness or risk management.[15]

The types of assessment—and the kinds of program and policy initiatives—in which public health professionals may engage include:

- Improving the public health infrastructure, systems, and strategies to be more responsive to extreme weather events (e.g., developing early warning systems and evacuation plans for extreme weather events, ensuring water safety, optimizing sanitation);
- Conducting population risk assessments to identify regions and communities that are vulnerable to climate change and institute preventive programs;
- Promoting healthy and sustainable built environments;
- Assessing public health preparedness for climate change events and filling gaps in knowledge, resources, and skills to ensure a competent workforce;
- Mobilizing community partnerships to create community-centered programs, education, and resources to address climate change;
- Providing infection and disease surveillance, immunization programs, and low-toxicity vector control/eradication programs;
- Creating health-promoting communities that have green spaces, energy-efficient housing, and access to nutrition and clean water;
- Enabling individual and business access to clean technologies; and
- Educating the public about personal behaviors that will decrease fossil fuel use.

Health Impact Assessment. In addition to developing programs and advocating for climate-friendly policies, public health professionals may also employ health impact assessments (HIAs)—a process to facilitate communications between public health professionals and decision-makers outside of public health to consider the health impacts of proposed projects, policies or programs.[16-18] According to the Centers for Disease Control and Prevention (CDC), the major steps of an HIA include:

- Screening to identify projects or policies that require an HIA;
- Scoping to identify potential health effects;
- Assessing to identify who might be affected and how;
- Developing recommendations to avoid or minimize adverse health effects;
- Reporting the results to relevant decision-makers; and
- Monitoring and evaluating to determine the effects of the HIA on decision-making.[18]

Education Challenges

There are two major public health education challenges: one involves preparing the public health workforce and the other involves providing appropriate climate change education to the public.

Local health departments must protect vulnerable populations from the increasing heat, the severe storms, droughts, and flooding that climate change is bringing to their communities. Are we training the public health workforce—in our schools and through our continuing education efforts—to do so? It isn't clear, although climate change professional development has been increasingly prioritized. In 2017, the theme of the annual meeting of the US's largest public health professional organization, the American Public Health Association (APHA), will be climate change. This is the first year in APHA's history that climate change has been featured as a predominant theme. Climate change is also an emerging priority in international policy guidelines. For example, the World Health Organization has called for the inclusion of climate change education in healthcare workforce education programs in developing countries.[19] Health workforce development was also identified as a priority area in the CDC's Policy on Climate Change and Public Health.[20] Public health workforce training may involve a specific kind of health literacy (an "eco-health literacy") about how health may be shaped by ecosystems and how medical and public health systems may need to be modified to address changing environmental conditions.

The concepts of "preparedness" are clear to public health professionals and are already shaped by climate change concerns, although the level of engagement in climate change activities and actual preparedness is not clear. In a 2011 article that featured interviews with several public health experts, Cooney stated that, *"The rise in illness and mortality reported during heat waves, hurricanes, and other extreme weather events indicates the public health community in the United States, and elsewhere, is not yet prepared to handle the increase in human disease predicted to arise with climate change...."*[21]

Referring to a survey of 174 local public health directors about climate change in 2011-2012, Roser-Renouf and colleagues found considerable apathy that they suspected was fueled by lack of resources and knowledge.[22] They also found that less than half of the directors said that dealing with climate change was a priority in their departments. The directors perceived that they lacked adaptation expertise, that climate change was not a departmental priority, and that they did not have access to programming and adaptation-related services.[22] The authors concluded that, "*Without increases in funding to build expertise in risk assessment, and in program design and evaluation, however, adaptation may continue to stall."*[22] While the survey was limited by a 49% response rate, it suggested that there were important gaps in prioritizing and preparing for climate change among the nation's public health directors. In this volume, Grossman also points to gaps in knowledge and resources in a survey of Illinois public health directors about climate change preparedness (page 46).

The CDC's Policy on Climate and Health also prioritized the need to educate the public about climate change.[20] Obviously, a limit to such education is the capacity of public health professionals themselves. Roser-Renouf and colleagues, who conducted the survey of local public health directors, suggested that some of the directors' knowledge and attitude gaps may reflect their perceptions about the public's beliefs about climate change.[22]

Surveys of Americans would suggest that the local public health directors are correct about how low climate change may be as a priority to citizens. For example, according to a national survey of 1,045 adults in 2013, it is estimated that 63% of Americans believe that climate change is happening.[23] Forty-nine percent of those surveyed stated that climate change—if it is happening—is caused mostly by human activities.[23] Despite the fact that almost all scientists agree that climate change is occurring as a result of human actions, and that it has potentially dire consequences,[1-5] only 42% of Americans stated that most scientists think climate change is happening.[23] Fifty-one percent of Americans in the survey were "somewhat" or "very worried" about climate change.[23]

The American public (and the larger global community) requires public health education about how climate change could affect them. As discussed by Tupper (page 60) elsewhere in this volume, such communication needs to be targeted to specific groups, accounting for varying levels of understanding, cultural and ethnic differences, vulnerability to the health effects of climate change, and other factors.[15] Messages should empower people to access and use necessary health resources.[15] Messages with frightening scenarios may elicit despair and helplessness, so they should be designed to minimize fear and lead to constructive behaviors.[15]

Among the messages that public health professionals may send is that there are direct and indirect benefits, beyond climate change mitigation and resilience, to many proposed actions.[15] For example, policies that reduce emissions of greenhouse gases from power plants can also improve air quality, with direct benefits for respiratory and cardiovascular health. And personal behaviors that reduce travel by fossil-fueled vehicles and increase walking, bicycling, and public transit use promote physical activity.

Involvement in Climate Change Action is Natural for Public Health Professionals

The involvement of public health professionals to mitigate the effects of

The Language of Climate Change

The terms "global warming" and "climate change" are often used interchangeably, but they have different meanings. "Weather" and "climate" are also sometimes confused, but they refer to different events, with different dimensions and time scales.

Global warming refers to the increased temperature trend on Earth since the early 20th Century (mostly since the late 1970s). It is a human-made condition, caused by the increase in fossil fuel emissions (especially carbon dioxide) since the Industrial Revolution. Fossil fuels add heat-trapping gases to the Earth's atmosphere. Since 1880, the average surface temperature on Earth has increased by about 0.8 °C (1.4 °F), relative to the mid-20th Century baseline (1951-1980). Global warming is causing climate patterns to change but it represents only one aspect of climate change.

Climate change refers to any significant change in climate that lasts for an extended period of time. It includes a broad range of global phenomena caused by burning fossil fuels. These phenomena include the increased temperature trends referred to as global warming, acidification of the oceans, loss of ice masses, shifts in biodiversity, and extreme weather events.

Weather refers to atmospheric conditions that occur locally over short periods of time—from minutes to hours or days. Examples of weather are rain, snow, clouds, winds, or thunderstorms.

Climate is long-term and global averages of temperature, humidity, and rainfall patterns over seasons, years, or decades.

Climate change is also associated with many social determinants of health, including food and water availability and secure and stable shelter.

The Lancet Countdown: Tracking Progress on Health and Climate Change

The Lancet Countdown: Tracking Progress on Health and Climate Change is an international, multi-disciplinary research collaboration between academic institutions in Europe and China. Its foundation is that climate change is *"…the greatest global health opportunity of the 21st century."* While the *Lancet Countdown* scholars state that climate change has the capacity to reverse the health gains from economic development in low- and middle-income countries, they also state that there is a potential of health co-benefits related to making societal and individual changes in response to climate change. Climate change thus presents challenges and opportunities.

The *Lancet Countdown* will track five focus areas annually: (1) the health impacts of climate hazards; (2) health resilience and adaptation; (3) health co-benefits of climate change mitigation; (4) economics and finance; and (5) political and broader engagement.

In 2015, the *Lancet Countdown* identified nine strategies for governments over the next five years:[1]

- Invest in climate change and public health research, monitoring, and surveillance;
- Scale-up financing for climate resilient health systems worldwide;
- Protect cardiovascular and respiratory health by ensuring a rapid phase-out of coal from the global energy mix;
- Encourage a transition to cities that support and promote lifestyles that are healthy for individuals and the planet;
- Establish the framework for a strong, predictable, and international carbon pricing mechanism;
- Rapidly expand access to renewable energy in low- and middle-income countries;
- Support accurate quantification of the avoided burden of disease, reduced health-care costs, and enhanced economic productivity associated with climate change mitigation;
- Ensure that health and climate considerations are thoroughly integrated into government strategies; and
- Implement an international agreement that supports countries in transitioning to a low-carbon economy.

Some information about this initiative can be found at http://www.thelancet.com/climate-and-health.

References

1. Watts N, Adger N, Agnolucci P, et al. Health and climate change: policy responses to protect public health. Lancet 2015;386:1861-914.

climate change and promote resilience and adaptation is a natural one. Public health professionals are trained to engage stakeholders to build strong communities and use evidence-based approaches to create programs and policies that encourage sustainable development and healthy environments. They are also trained to encourage changes in individual lifestyles in a manner that is culturally competent and respectful. Public health professionals already think about the social, economic, and environmental systems in which we live. They understand that vulnerabilities vary and that people with clean air in one region may not appreciate the problems associated with the lack of clean air in another region. Public health professionals focus on the vulnerable, for the good of all. They know that we all live in the same space and that it has to be healthy.

For More Information

Two Minnesota resources provide examples of public health actions to address climate change:

1. Minnesota Department of Health's Minnesota Climate & Health Program website has many resources that explain some of the consequences of climate change (e.g., water quality, air quality), a professional toolkit, training resources, videos, and other materials. It is at http://www.health.state.mn.us/divs/climatechange.
2. Minnesota's Environmental Quality Board has a 44-page report that provides the foundation of Minnesota's state climate action planning. It is at https://www.eqb.state.mn.us/sites/default/files/documents/CSEO_EQB.pdf.

References

1. Intergovernmental Panel on Climate Change. Working Group II. Climate change 2014: impacts, adaptation, and vulnerability. [Internet]. 2014. Available from: https://www.ipcc.ch/report/ar5/wg2.
2. Intergovernmental Panel on Climate Change. Working Group III. Climate change fifth assessment report. Mitigation of climate change. [Internet]. 2014. Available from: https://www.ipcc.ch/report/ar5/wg3.
3. Intergovernmental Panel on Climate Change. Working Group I. The physical science basis. [Internet]. 2013. Available from: http://www.climatechange2013.org.
4. American Association for the Advancement of Science Climate Science Panel. What we know. [Internet]. Available from: http://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf.
5. The National Aeronautics and Space Administration (NASA). NASA, NOAA Data show 2016 warmest year on record globally. [Internet]. 2017. Available from: https://www.giss.nasa.gov/research/news/20170118.
6. National Oceanic and Atmospheric Administration. National Centers for Environmental Information. Global climate change indicators. [Internet]. Available from: https://www.ncdc.noaa.gov/monitoring-references/faq/indicators.php.
7. Center for Climate and Energy Solutions. The basics. [Internet]. Available from: https://www.c2es.org/science-impacts/basics.
8. World Health Organization. Climate change and health. [Internet]. 2016. Available from: http://www.who.int/mediacentre/factsheets/fs266/en.
9. Huber DG, Gulledge J. Extreme weather and climate change: understanding the link and managing the risks. Center for Climate and Energy Solutions. [Internet]. 2011. Available from: https://www.c2es.org/publications/extreme-weather-and-climate-change.
10. Patz JA, Frumkin H, Holloway T, et al. Climate change: challenges and opportunities for global health. JAMA 2014;312(15):1565-80. Available from: http://z.umn.edu/patz.
11. Watts N, Adger N, Agnolucci P, et al. Health and climate change: policy responses to protect public health. Lancet 2015;386:1861-914.
12. Mueller V, Gray C, Kosec K. Heat stress increases long-term human migration in rural Pakistan. Nature Climate Change 2014;4(3):182-5. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4132829.
13. Kelley CP, Mohtadi S, Cane MA, et al. Climate change in the Fertile Crescent and implications of the recent Syrian drought. Proc Natl Acad Sci 2015;112(11):3241-6. Available from: http://z.umn.edu/kelley.
14. US Global Change Research Program. National climate assessment. [Internet]. 2014. Available from: http://nca2014.globalchange.gov.
15. Frumkin H, Hess J, Luber G, et al. Climate change: the public health response. Am J Public Health;2008:98(3):435-45. Available from: http://z.umn.edu/frumkin.
16. Brown H, Spickett J, Katscherian D. A health impact assessment framework for assessing vulnerability and adaptation planning for climate change. Int J Environ Research Public Health 2014;11(12):12896-914. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4276652/.
17. Minnesota Department of Health. Health impact assessment (HIA). [Internet]. Available from: http://www.health.state.mn.us/divs/hia.
18. Centers for Disease Control and Prevention. Health impact assessment. [Internet]. 2016. Available from: https://www.cdc.gov/healthyplaces/hia.htm.
19. World Health Organization. WHO workplan on climate change and health aims and objectives: 2014-2019. [Internet]. 2015. Available from: http://www.who.int/globalchange/health_policy/climate-change-and-health-workplan-2014-2019.pdf?ua=1.
20. Centers for Disease Control and Prevention. CDC policy on climate and health. [Internet]. 2014. Available from: https://www.cdc.gov/climateandhealth/policy.htm.
21. Cooney CM. Preparing a people: climate change and public health. Environ Health Perspect 2011;119(4): A166–A171. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3080957/.
22. Roser-Renouf C, Maibach EW, Li J. Adapting to the changing climate: an assessment of local health department preparations for climate change-related health threats, 2008-2012. PloS One 2016;11(3):e0151558. Available from: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0151558.
23. Leiserowitz A, Maibach E, Roser-Renouf C, et al. Climate change in the American mind. Yale University and George Mason University. New Haven, CT: Yale Project on Climate Change Communication. [Internet]. 2013. Available from: http://environment.yale.edu/climate-communication/files/Climate-Beliefs-April-2013.pdf.

Cities Take the Lead on Climate Change

Cities may be more affected by climate change than rural or suburban areas because of their relatively higher temperatures. Cities can sometimes be as much as 10 degrees warmer than surrounding non-urban areas because of reduced vegetation and green spaces; heat-absorbing surfaces, like pavement; heat-reflecting surfaces, like those on buildings; and skyscrapers that obscure air flow. Urban areas contain about half of the world's population and that percentage will increase to about two-thirds by 2050. Cities produce 80% of the world's economic output and 70% of its greenhouse gas emissions.

Because of their vulnerability—and because they are home to so many people—cities have adopted a range of measures, from requiring more efficient buildings, creating more green spaces, and building more bike paths and clean-energy public transit opportunities. According to ICLEI (http://www.iclei.org), a global network of more than 1,500 cities, towns, and regions committed to building a sustainable future, cities are moving ahead, while some federal governments move much more slowly. ICLEI identifies some of the most ambitious cities as Seattle, Oslo, Stockholm, and Copenhagen—all of which have vowed to become carbon-neutral. Copenhagen, in fact, has pledged to do so by 2025, 15 years before Stockholm and 25 years before the other cities. Among Copenhagen's measures have been district heating systems, replacing streetlights with LEDs, and making it easier for cyclists to get around.

Another global city-led initiative to address climate change in urban areas is the United Nation's Compact of Mayors (https://www.compactofmayors.org). Among its hundreds of partner cities that are developing climate action plans with community input are 133 cities in the US, including the Midwestern/Plains cities of Ashland WI; Chicago IL; Des Moines IA; Dubuque IA; Evanston IL; Iowa City IA; Grand Rapids MI; Minneapolis MN; St. Paul MN; and Wisconsin Rapids WI.

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Climate Change:
Environmental Effects

by Wendy L. Hellerstedt, MPH, PhD

During the last several decades, scientists have observed an alarming change in the climate that cannot be attributed to natural influences.[1-7] They agree that this climate change is anthropogenic (human-induced).[1-7] It is principally attributable to the increase of heat-absorbing greenhouse gases in our atmosphere since the Industrial Revolution. These gases have led to more heat being retained in the atmosphere and thus to increasing global average surface temperatures. Carbon dioxide (CO_2) may be the most important of these gases. CO_2 remains in the atmosphere for centuries and in the ocean—where it acidifies the water—for even longer. CO_2 is now above the symbolic and significant concentration of 400 parts per million in the atmosphere.[5]

The dramatic environmental effects that scientists agree are associated with climate change have been observed over the past few decades, not millennia.[2,4,5,8] The International Panel on Climate Change, summarizing the evidence about the impacts of climate change, concluded that, *"...changes in climate have caused impacts on natural and human systems on all continents and across the oceans."*[8] The following lists some of the impacts. Their categorization is arbitrary; further, these consequences of climate change are strongly interrelated.

Extreme Weather

Heat waves, droughts, floods, and cyclones have threatened the vitality of ecosystems and the life and health of humans. As the atmosphere and oceans warm, additional energy creates extreme weather. For example, warmer temperatures allow the atmosphere to hold more moisture, which can drive heavier downpours. Melting land-based ice, combined with warming oceans, fuels global sea level rise, which in turn amplifies storm surge and coastal flooding.[5,8]

Extreme weather results in large community and economic losses. Fifteen extreme weather events—each costing $1 billion or more—occurred in the US in 2016, causing $46 billion in aggregate damages. Even when adjusting for inflation, four of the five years with the most billion-dollar extreme weather events in the US have occurred since 2010.[10]

"...changes in climate have caused impacts on natural and human systems on all continents and across the oceans."

Heat. Earth is warming to a dangerous degree, which is why there are international efforts (e.g., the Paris Agreement and a new initiative by Bill Gates and other world leaders) to stop increased warming related to human use of fossil fuels. Fifteen of the 16 hottest years on record have been in the 21st Century.[5] Heat waves have become more frequent and intense, threatening human health, stressing water resources, and increasing energy demands.[8]

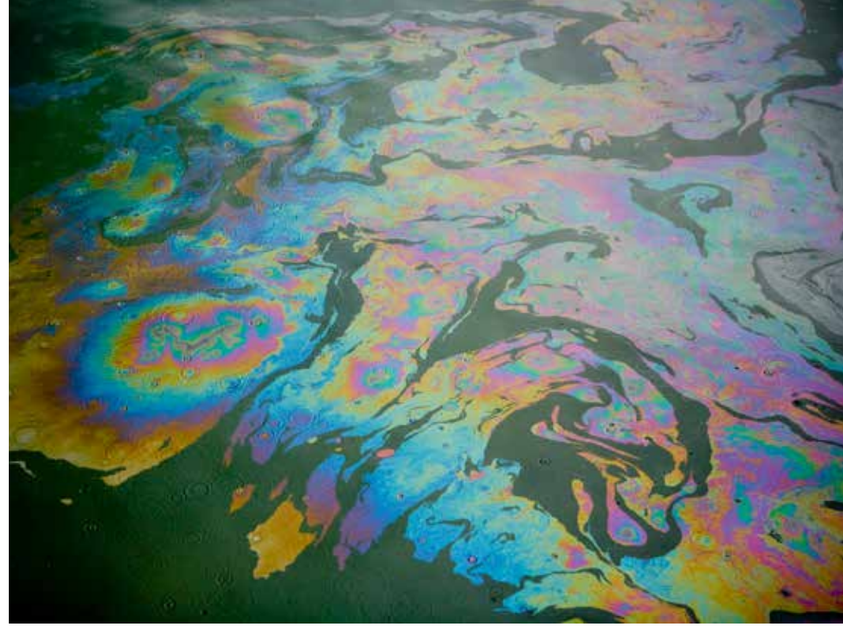
In 2016, record or near-record temperatures occurred in parts of the Middle East, North Africa, and Asia.[5] The highest temperature observed was 129°F in Mitribah (Kuwait) in July 2016; this was the highest temperature on record for Asia.[5] A late-season heat wave affected many parts of western and central Europe in 2016. For example, the temperature reached 113°F in Cordoba, Spain in September 2016.[5]

Precipitation. Drought and flooding are both concerns. The hydrological cycle accelerates with global warming. As heat energy accumulates in the deep ocean, more water evaporates, causing increased intensity and frequency of precipitation. Evaporation from soil may also be increased, causing drought. Models indicate that, if climate change continues at the same pace, the future will see more heavy deluges (with flooding) and more frequent and longer droughts.[5,8]

In 2016, much of southern Africa began the year in severe drought. For the second year in a row, rainfall was 20-60% below average for the summer rainy season (October to April) in 2015/2016.[5] 2016 was also the driest on record over the Amazon Basin and there was significant drought in northeast Brazil, Central America, and northern South America.[5]

Conversely, China averaged its wettest year on record, with the annual mean rainfall 16% above the long-term average.[5] Not surprisingly, the Yangtze basin in China experienced its most significant flood season since 1999, with some tributaries experiencing record flood levels.[5]

Lightning. Lightning results from the amount of water or precipitation in the atmosphere and the instability of the atmosphere, a situation that allows air to rise rapidly. A 2014 study estimated that, for every average global increase of one degree Celsius, there would be a 12% increase in lightning.[11] A significant increase in global temperatures (say, an average of three degrees Celsius) was estimated to increase the number of lightning strikes by 50%.[11] Half of all of the wildfires in the US are caused by lightning, so this could have a significant impact on the number of wildfires, especially in remote areas.



Ocean Health

Since 1955, over 90% of the excess heat trapped by greenhouse gases has been stored in the oceans.[1] The rest of this energy goes into melting sea ice, ice caps, and glaciers, and into warming the Earth's land mass.[12] A very small fraction of this thermal energy goes into warming the atmosphere.[12] According to a 2017 study by Henson, et al., more than half of the world's oceans could experience multiple symptoms of climate change over the next 15 years, including rising temperatures, acidification, lower oxygen levels, and decreasing food supplies.[13] By mid-century, if there isn't significant change in global warming, more than 80% of the oceans could be severely damaged.[13] The Arctic, already among the most rapidly warming areas on Earth, may be one of the regions most severely affected.[13]

Ocean Temperature. Globally, average sea surface temperatures in 2016 were the warmest on record.[5] Global ocean heat content in 2016 was the second highest on record after 2015.[5] It reached new record highs in the Northern Hemisphere in 2016.[5] Warmer ocean temperatures pose several threats (e.g., rising sea levels), including destruction of coral reefs. For example, during 2015–2016, record temperatures in Australia triggered a pan-tropical episode of coral bleaching, the third global-scale event since mass bleaching was first documented in the 1980s.[14] The distinctive geographic footprints of recurrent bleaching on the Great Barrier Reef in 1998, 2002, and 2016 were determined by the spatial pattern of sea temperatures in each year.[14] Water quality and fishing pressure had minimal effect on the unprecedented bleaching in 2016, which scientists concurred was almost solely related to ocean temperatures.[14]

Amount of Arctic Sea Ice. The seasonal maximum of sea ice in 2016 (14.52 million square kilometers in March), was the lowest in the 1979-2016 satellite record.[5] The 2016 autumn freeze-up was exceptionally slow, with sea ice extent uncharacteristically contracting for a few days in mid-November.[5]

Sea Level Rise. Global sea levels rose very strongly during the 2015/2016 El Niño, rising about 15 millimeters (mm) between November 2014 to a new record high in February 2016.[5] This was well above the post-1993 trend of 3-3.5 mm per year.[5]

In order of importance, the sea level rise has been driven by: expansion of water volume as the ocean warms, melting of mountain glaciers in most regions of the world, and losses from the Greenland and Antarctic ice sheets.[6] All of these factors are the result of a warming climate. The

...global average surface temperature is simply an index of the state of a very complicated system, just like our body temperature is an index of a very complicated system. When our body temperature increases, it is telling us that something is amiss in the system.

sea level has risen about eight inches in the last 100 years, making coastal storms more damaging and accelerating erosion. If the current emissions of greenhouse gases continue, it is estimated that the sea level may rise another 1.5-3 feet by 2100.[6] Globally, the future sea level rise is likely to range from 1-4 feet.[6] It could be even higher if glaciers in Greenland or Antarctica melt especially quickly.[6]

The short-term effects of sea level rise is likely to increase storm surge, making hurricanes and other severe storms more destructive. In the US, for example, coastal flooding from high tides has increased by 364-925% on all three US coasts over the last 50 years.[10] Sea level rise may also contaminate groundwater supplies with saltwater (which could, in turn, affect the quality of crop lands). In the longer term, many coastal communities may become uninhabitable, which could be most difficult for people who live in small island nations, where higher ground may be limited, thus potentially necessitating migration to other countries.

Acidification. CO_2 dissolves in water to form a weak acid. The oceans have absorbed about one-third of the CO2 from fossil fuel emissions, leading to a steady decrease in ocean pH levels. Thus, the chemical balance of nearly all sea water has shifted to a more acidic state (i.e., lower pH).[12] Henson and colleagues found that some parts of the globe's oceans are already experiencing climate-driven changes beyond their natural limits; they further reported that 99% of the open ocean is experiencing acidification.[13]

Acidification has posed risks to marine ecosystems, especially polar ecosystems and coral reefs. It has also had negative effects on the physiology, behavior, and population dynamics of individual species, from phytoplankton to animals.[8,12] For example, some marine organisms (e.g., corals, some shellfish) have shells made of calcium carbonate which are likely to dissolve in acid. As the acidity of sea water increases, it thus becomes more difficult for these organisms to form or maintain their shells.

The Arctic Ocean is the first ocean where such rapid and large-scale increases in acidification have occurred, at least twice as fast as that observed in the Pacific or Atlantic oceans.[15] The effects of acidification pose challenges to infrastructure, businesses, and communities, particularly in countries already struggling to meet the basic food, water, shelter, and security needs of their citizens.

Reducing greenhouse gas emissions could significantly delay future changes, giving marine organisms more time to migrate or adapt.[16] According to Henson, et al., "Mitigation slows the pace at which multiple drivers emerge, allowing an additional 20 years for adaptation in marine ecological and socio-economic systems alike."[13] If, however, the globe continues to warm, there will be hotter ocean temperatures, lower pH, and less oxygen than has ever naturally occurred. This may mean that some organisms will be forced to migrate, evolve as a species, or face extinction.

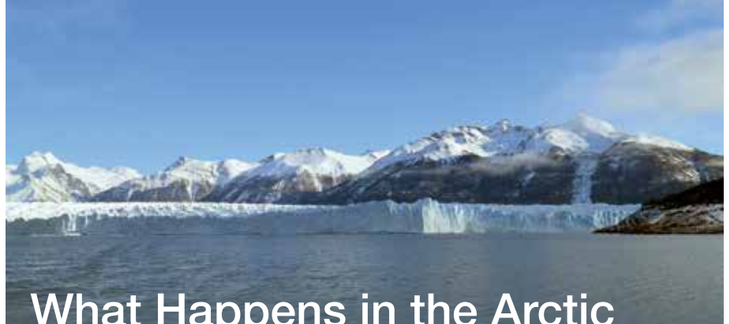
Land, Air, and Water

Land Degradation. Among the many studies that have documented climate-related land degradation is that of Guiot and colleagues. Using historical data and computer models, they predicted that Southern Spain will become a desert and deciduous forests will vanish from much of the Mediterranean basin unless the pace of climate change slows.[17] Using pollen records to gauge the effects of temperatures on plant life, they suggested that, if global temperatures continue to rise, deserts would expand in Spain, North Africa, and the Near East, while vegetation in the region would undergo significant changes.[17]

In addition to the potential effects of ocean degradation on the salination of soil, climate change has also amplified the threat of wildfires in many places. For example, in the western US, both the amount of area burned and the length of the wildfire season have increased in the past decades. Earlier spring snowmelt and higher spring and summer temperatures have also contributed to this change.[2] As discussed elsewhere in this volume by Josiah (page 14), wildfires and other climate-related conditions are threatening the health of our forests.

Air Pollution. The population continues to increase and, with it, there is an increased demand for energy. If we meet that demand by burning more fossil fuels, air pollution will increase to dangerous levels.[2,6-8] We'll see increased particulates, oxides of nitrogen and sulfur, volatile organic hydrocarbons, and more ozone.[8] Ground-level ozone may be especially harmful to the health of children, whose short stature means that they are closer to the ground.

Water Availability. Water may become less available because of changes in precipitation patterns, loss of snowpack, and earlier snowmelt.[8] Warmer temperatures can increase water demands for agriculture, energy, and human and animal consumption. Reductions in renewable surface water and groundwater may be most significant in dry, sub-tropical regions.[8] Flooding from heavier rainfall events can also overcome wastewater treatment systems and spread agricultural runoff and waste into water bodies.[8] This can damage human health and economies, especially in areas with limited reservoirs and water treatment plants.



Ice Flow Melting

Source: https://pixabay.com/en/glacier-tongue-glacier-lake-water-983891/.

What Happens in the Arctic Does Not Stay in the Arctic

According to the Royal Society (and other groups of scientists), the Arctic has been warming at twice the global rate, largely driven by reductions in summer and fall sea ice. Reduced ice absorbs more solar warmth and that reduces ice levels further. Spring snow on Arctic land is disappearing earlier and the Greenland Ice Sheet is thinning. Sea ice has decreased dramatically in the Arctic since 1978—the yearly minimum Arctic sea extent (which occurs in early to mid-September) has decreased by more than 40%. The average glacier lost about 39 feet of thickness since 1997. Ice cover expands again each Arctic winter but the ice is thinner than it used to be. Estimates of past sea ice extent suggests that this decline may be unprecedented in the past 1,450 years. Sometime in the 21st Century, perhaps within the next few decades, the Arctic will likely be ice-free in the summer. According to the Royal Society, *"Because sea ice is highly reflective, warming is amplified as the ice decreases and more sunshine is absorbed by the darker underlying ocean surface."*

What does the loss of Arctic sea ice have to do with snowfall and rain in the US? Plenty. As described by Yereth Rosen, the amplified Arctic warming is significantly affecting weather patterns much further south. Rosen stated that it has been theorized that with temperature differences between north and south smaller than in the past *"...and with more open water and more cloud cover sending and holding moisture in the Arctic atmosphere—weather systems are more frequently distorting the normally west-to-east jet streams into meandering loops, causing more stationary patterns and more frequent extreme events well south of the Arctic."* The rapid warming of the Arctic is thus slowing the jet stream, causing a wavy pattern that brings warm weather to the far north and cold weather to the middle latitudes.

For More Information

1. The Royal Society. Why is Arctic sea ice declining and Antarctic sea ice is not? [Internet]. Available from: https://royalsociety.org/topics-policy/projects/climate-change-evidence-causes/question-12/.
2. Rosen Y. What does a warming Arctic have to do with weather in New England? Plenty. [Internet]. 2016. Available from: https://www.adn.com/science/article/chemical-analysis-links-new-england-precipitation-warming-arctic/2016/02/29/.
3. Biello D. What will ice-free Arctic summers bring. Scientific American. [Internet]. 2012. Available from: https://www.scientificamerican.com/article/arctic-sea-ice-loss-implications/.

Loss of Biodiversity

Climate change endangers animals and plants if they are forced to shift their habitats to higher elevations or higher latitudes if they cannot survive in their current locations. There is evidence, for example, that terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, numbers, and species interactions.[8]

Reducing greenhouse gas emissions could significantly delay future changes.

Many species may face extinction because of climate change and other stressors (e.g., pollution) that have affected the composition, structure, and function of their ecosystems.

Urban conducted a meta-analysis of 131 research projects that predicted species extinctions.[18] He concluded that one in six species now alive on the planet could become extinct as a result of climate change.[18] Extinction risks were highest in South America (which could lose 23% of its species), and Australia and New Zealand, which could each lose about 14%.[18] North America was least affected, with a projected risk of losing 5% of its species.[18] Urban also warned that species that were not directly threatened by extinction could experience substantial changes in number, distribution, and interactions because of climate change.[18] Such changes, he noted, could affect ecosystems and their service to humans.[18]

A recent example of potential extinction in the US is the rusty-patched bumblebee. It has disappeared from about 90% of its geographic habitat in the past 20 years. It was once common on the East Coast and much of the Midwest where it played a crucial role as a pollinator of crops and wild plants.[19] It was identified as an endangered species in the US in March 2017.[19]

A Future of Surprises and Tipping Points?

The amount and type of climate change that occurs by the end of the 21st Century depends on our choices now. If we don't make much progress in cutting fossil fuel emissions, temperatures on Earth could

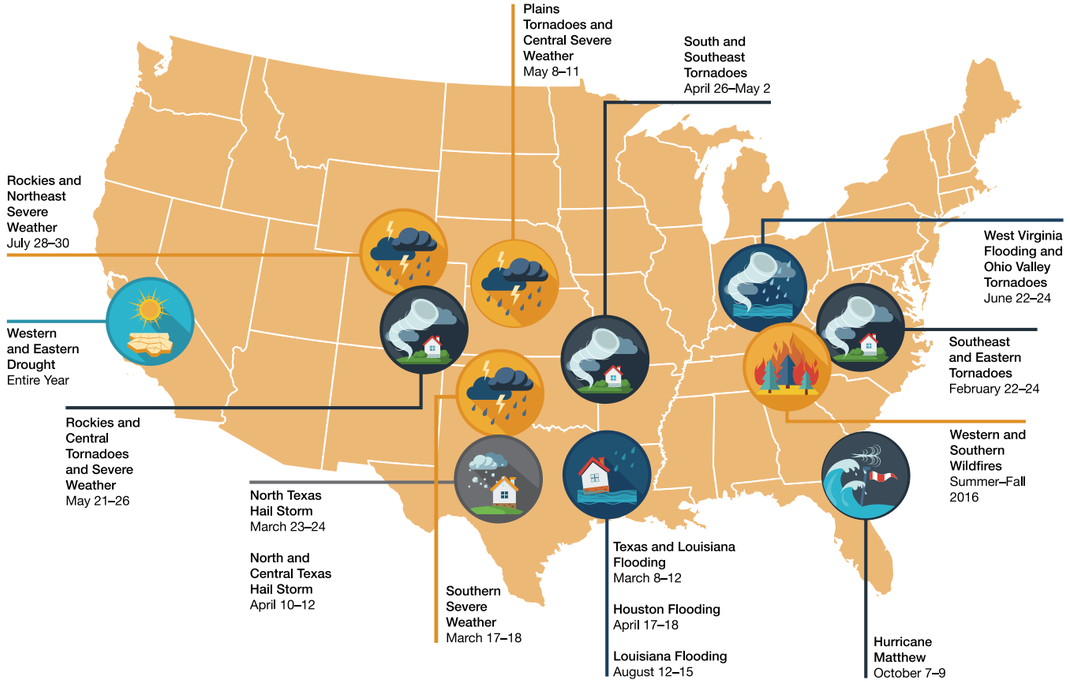
Weather-related Disasters Inflict Heavy Human and Economic Costs

Globally, weather-related disasters in the past two decades have killed more than 600,000 people, wounded 4.1 billion others, and cost at least $1.9 trillion dollars, according to a summary of weather-related events from 1995-2015 compiled by the United Nations (UN). The UN recorded an average of 335 weather-related disasters every year over the last two decades, which is at least double the number from the previous 10 years. Floods accounted for 56% of all the weather-related disasters, affecting about 2.3 billion people (mostly in Asia). Storms, however, took the heaviest toll on lives, causing about 242,000 deaths. Droughts (mostly in Africa) affected about 1.1 billion people in the past two decades, leading to hunger, malnutrition, and disease, as well as agricultural failure and long-lasting under-development of resources.

The report cited the rising temperature of oceans and melting glaciers as two major causes of extreme weather and noted that reducing greenhouse gas emissions would help reduce future damage and losses linked to climate change. It also provides guidance for other mitigation efforts. For example, the report stated that flood mitigation policies have high potential because the technology to control them (e.g., dikes, dams, early warning systems) already exist. The UN report is at https://www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf.

The UN reported that the US had the highest number of weather-related disasters in the past decade, but China and India have been most severely affected, enduring floods that have affected billions of people. Another report from the US National Oceanic and Atmospheric Administration indicated that, in 2016, there were 15 major weather and climate disaster events in the US, with losses exceeding $1 billion each. These events included a drought, four floods, eight severe storms, a tropical cyclone, and a wildfire. Collectively, they resulted in the deaths of 138 people in the US (https://www.ncdc.noaa.gov/billions).

US 2016 Billion-Dollar Weather and Climate Disasters



Source: NOAA National Centers for Environmental Information (NCEI) US Billion-Dollar Weather and Climate Disasters (2017). https://www.ncdc.noaa.gov/billions

rise between 4.7°F-8.6°F (2.6°C-4.8°C) by the end of the century, compared to the average temperature at the end of the 20th Century.[1] Warming in the US is expected to be higher than the global average if fossil fuel emissions rates continue.

Even though we have the opportunity to avoid some of the effects of climate change if we make large-scale and personal changes in our consumption,[7,16] we will still face many climate-related environmental effects in the coming decades. In addition, rapid warming can increase the risks of climate "surprises" or "tipping points." Examples of these tipping points include the potential injection of methane into the atmosphere from thawing permafrost that could further accelerate warming, or the loss of important ecosystems, such as large areas of the boreal or Amazon forests, that occurs as temperatures warm and precipitation patterns change.[8]

John Holdren, Professor in the Department of Earth and Planetary Sciences at Harvard University and former Director of the White House Office of Science and Technology Policy, said that the global average surface temperature is simply an index of the state of a very complicated system, just like our body temperature is an index of a very complicated system. When our body temperature increases, it is telling us that something is amiss in the system. The same is true of the increase of the globe's surface temperature.[20]

For More Information

1. World Metereological Organization. WMO statement on the state of the global climate in 2016. [Internet]. 2017. Available from: http://library.wmo.int/opac/doc_num.php?explnum_id=3414.
2. The Guardian. From floods to forest fires: a warming planet in pictures. Available from: https://www.theguardian.com/environment/gallery/2016/jun/03/from-floods-to-forest-fires-a-warming-planet-in-pictures#img-3.
3. Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. The Lancet. 2015;386(10007):1973-2028. Available from: https://www.rockefellerfoundation.org/report/safeguarding-human-health-anthropocene-epoch/.

References

1. Intergovernmental Panel on Climate Change. Working Group I. The physical science basis. [Internet]. 2013. Available from: http://www.climatechange2013.org.
2. American Association for the Advancement of Science Climate Science Panel. What we know. [Internet]. Available from: http://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf.
3. The National Aeronautics and Space Administration (NASA). NASA, NOAA Data show 2016 warmest year on record globally. [Internet]. 2017. Available from: https://www.giss.nasa.gov/research/news/20170118/.
4. National Oceanic and Atmospheric Administration. National Centers for Environmental Information. Global climate change indicators. [Internet]. Available from: https://www.ncdc.noaa.gov/monitoring-references/faq/indicators.php.
5. World Meteorological Organization. WMO statement on the state of the global climate in 2016. [Internet]. 2017. Available from: http://library.wmo.int/opac/doc_num.php?explnum_id=3414.
6. The Royal Society and the US National Academy of Sciences. Climate change evidence and causes. [Internet]. 2014. Available from: https://royalsociety.org/topics-policy/projects/climate-change-evidence-causes/.7.
7. Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. The Lancet. 2015 Nov 14;386(10007):1973-2028. Available from: https://www.rockefellerfoundation.org/report/safeguarding-human-health-anthropocene-epoch/.
8. Intergovernmental Panel on Climate Change. Working Group II. Climate change 2014: impacts, adaptation, and vulnerability. [Internet]. 2014. Available from: https://www.ipcc.ch/report/ar5/wg2.
9. National Oceanic and Atmospheric Administration. National Centers for Environmental Information. State of the climate. [Internet]. 2017. Available from: https://www.ncdc.noaa.gov/sotc.
10. National Oceanic and Atmospheric Administration. National Centers for Environmental Information. Billion-dollar weather and climate disasters: table of events. [Internet]. 2017. Available from: https://www.ncdc.noaa.gov/billions/events.
11. Romps DM, Seeley JT, Vollaro D, et al. Projected increase in lightning strikes in the United States due to global warming. Science 2014;346(6211):851-4. Available from: http://www.atmos.albany.edu/facstaff/vollaro/pubs/Romps.et.al-SCI2014.pdf.
12. Ocean Scientists for Informed Policy. Ocean warming. [Internet]. Available from: http://www.oceanscientists.org/index.php/topics/ocean-warming.
13. Henson SA, Beaulieu C, Ilyina T, et al. Rapid emergence of climate change in environmental drivers of marine ecosystems. Nature Communications 2017 [online]. Available from: http://www.nature.com/articles/ncomms14682.
14. Hughes TP, Kerry JT, Álvarez-Noriega M, et al. Global warming and recurrent mass bleaching of corals. Nature 2017;543(7645):373-7.
15. Qi D, Chen L, Chen B, et al. Increase in acidifying water in the western Arctic Ocean. Nature Climate Change 2017;7(3):195-9. Available from: http://www.nature.com/nclimate/journal/v7/n3/full/nclimate3228.html.
16. Intergovernmental Panel on Climate Change. Working Group III. Climate change fifth assessment report. Mitigation of climate change. [Internet]. 2014. Available from: https://www.ipcc.ch/report/ar5/wg3/.
17. Guiot J, Cramer W. Climate change: the 2015 Paris Agreement thresholds and Mediterranean basin ecosystems. Science 2016;354(6311):465-8.
18. Urban MC. Accelerating extinction risk from climate change. Science 2015;348(6234):571-3. Available from: http://z.umn.edu/urbanext.
19. US Fish & Wildlife Service. Endangered species. Rusty patched bumblebee. [Internet]. 2017. Available from: https://www.fws.gov/midwest/Endangered/insects/rpbb/index.html.
20. Yale Environment 360. From Obama's top scientist, words of caution on climate. [Internet]. 2016. Available from: http://e360.yale.edu/features/obama_top_scientist_words_of_caution_climate_john_holdren.

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Climate Change and Nebraska's Tree and Forest Resources

by Scott Josiah, MS, PhD


Scott Josiah

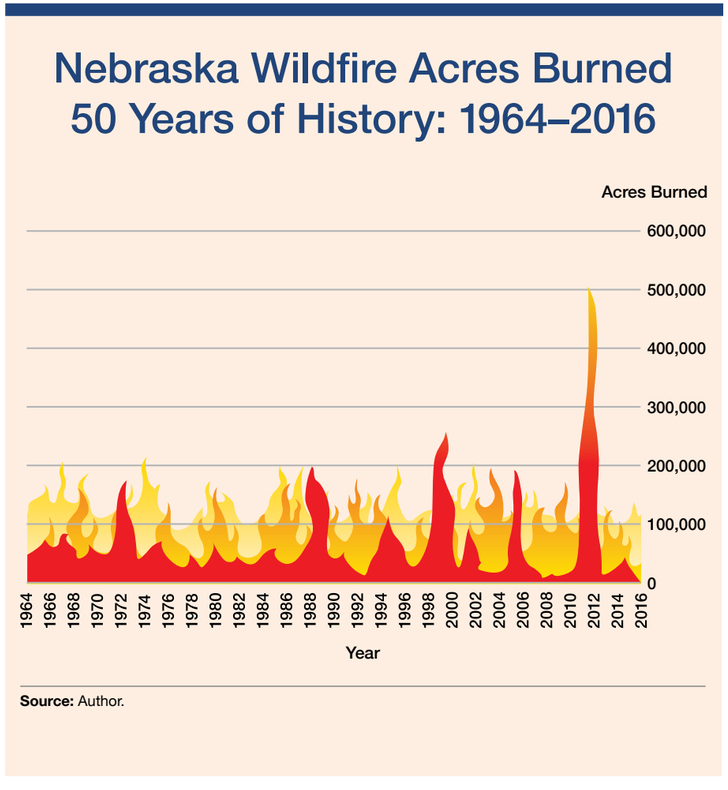
According to the US Department of Agriculture (USDA) Forest Service, forests in Nebraska occupy approximately 1.5 million acres, with an additional 1.5 million acres of non-forest land with trees.[1] Nebraska's forest types are unique in that they generally exist on the eastern, western, or southern edges of their native ranges, and grow under stressful conditions more often conducive to prairie ecosystems than to forests. These tree and forest resources provide critically important economic and ecosystem services.

Projected changes in Nebraska's climate will have,[2] and arguably are having, substantial and negative impacts on the state's tree and forest resources. Western states are warming faster than the global average.[3] Increased incidence and severity of drought, floods, wildfire, severe weather events, and higher temperatures will seriously affect the health, vitality, and resilience of individual trees and urban and rural forest ecosystems in Nebraska and across the Great Plains.

Wildfire Risks: Atmospheric Carbon, Trees, and Insects

More intense droughts compounded by higher temperatures and excessive forest fuel loads have already damaged trees and forests across the state. They have also substantially increased the risk to life and property due to catastrophic wildfires and have reduced sequestration and storage of atmospheric carbon. Large wildfire events have increased in frequency and size over the past 50 years (Figure 1).

Repeated, intense, and uncharacteristic wildfires occurring in the Ponderosa pine forests of the Pine Ridge in northwestern Nebraska have reduced forest cover from 250,000 acres to less than 100,000 acres since 1994. These forests burned so intensely that nearly all living trees were eliminated across large landscapes, eliminating seed sources and converting former forests to grassland. Intense wildfires driven by projected increases in temperature and drought will gravely threaten Nebraska's remaining pine forests. The Ponderosa Pine (*Pinus ponderosa* L.) forests in the Pine Ridge region and Niobrara River Valley of Nebraska are not only the easternmost extension of this species in North America, but also grow at considerably lower (and warmer) elevations than other Ponderosa pine forests in much of the western US. Their loss would eliminate unique genetic adaptations to low elevation and hotter conditions—exactly the genetic adaptations needed in a hotter, drier world.



Source: Author.

Climate-related Effects on Forest Health

Higher temperatures (especially at night), combined with drought, reduce the carbohydrate reserves that are essential for vigorous tree growth and pest resistance, often for several years. The population of pests (such as the Mountain Pine Beetle-*Dendroctonus species*) that used to be limited by very cold temperatures are now achieving much higher over-wintering success across the western US and Canada in part due to warmer winters. Nebraska's pine forests lost thousands of trees in the first decade of the 21st Century from Mountain Pine Beetle attacks, which were part of a massive outbreak of devastating forest fires across 35 million acres in North America. *Ips (species)* engraver beetles are currently attacking and killing surviving pine trees that were scorched by fire, as well as heat- and drought-stressed pines across the Pine Ridge region and Niobrara River Valley.

Increasing temperatures and drought also negatively affect urban forests, disproportionately killing non-native tree species (e.g., white pine, spruce) that are poorly adapted to these changing conditions. Urban trees are critically important components of green infrastructure that reduce high air temperatures and improve air quality. Reduced vigor and increased mortality of trees in urban areas will further decrease the capacity of urban forests to mitigate higher urban temperatures, increasing the risk of heat-related human health conditions.

Many climate models indicate that the frequency and intensity of these severe weather events will increase as a result of climate change, negatively impacting trees, forests, and public safety statewide.

Impact of Severe Weather Events on Trees and Forests

Like many states in the Great Plains, Nebraska has historically experienced a wide range of severe weather events. Many climate models indicate that the frequency and intensity of these severe weather events will increase as a result of climate change, negatively impacting trees, forests, and public safety statewide. The unprecedented flooding of 2011 along the Missouri River inundated 26,000 acres of bottomland forest in Nebraska for nearly the entire growing season. Many riparian forest species that are well adapted to temporary inundation, such as eastern cottonwood (*Populus deltoids var deltoids Bartr.*), willow (*Salix spp*.L.), box

Large-scale tree planting campaigns will be increasingly needed to replace trees and forests damaged or killed by severe weather events and more stressful climate conditions aggravated by climate change.

elder (*Acer negundo* L.), and sycamore (*Platanus occidentalis* L.), experienced widespread mortality due to the abnormally long period under water. Other severe weather events common to the Plains (tornadoes, straight line winds, ice and early winter snow storms, early fall and late spring freezes, etc.) already damage Nebraska's trees and forests. The projected increase in frequency and intensity of severe weather events will substantially increase the loss of trees and forests.

Changes in Forest/Crop Interactions

Windbreaks and forested riparian buffers—narrow bands of naturally occurring or intentionally planted trees that occur in an often treeless landscape dominated by annual crops—provide enormous environmental and economic services across the Great Plains and Midwest. These native and planted "forests" enhance air and water quality, protect adjacent crops from wind, reduce evapotranspiration and wind erosion on adjacent crop lands, and improve crop quality and yield. More than 30,000 miles of windbreaks in Nebraska alone provide nearly $80 million/year worth of increased yields, especially in drought years. The loss of windbreaks and forested riparian buffers from more frequent and more severe weather events will increase soil erosion, impair air and water quality, and decrease crop quality and yields across Nebraska.

Responses

There are multiple options available to address the challenges of climate change on Nebraska's trees and forests. Increasing the diversity of tree species and seed sources will enhance resilience of urban and conservation plantings (such as windbreaks and riparian buffers). Many coniferous forests across the western US have become unnaturally dense over the past century due to a lack of periodic low intensity fire and reduced harvesting. Thinning these overstocked coniferous forests reduces intra-tree competition for water, improves tree health and vigor, protects remaining islands of live forest stands isolated by previous wildfires, and decreases the risk of large-scale catastrophic crown fires. Prescribed fire (intentionally set low-intensity fires) can also be used to reduce forest fuel loads and thus the risk of stand-replacing wildfire.

Developing new products and markets for wood creates market drivers that support expanded forest thinning and harvesting operations. Trees contain carbon captured from the atmosphere over the past decades, whereas fossil fuels contain carbon captured millions of years ago. Burning wood for bioenergy applications only recycles carbon that would have been released to the atmosphere once the tree dies. But by burning fossil fuels, ancient, essentially new carbon is released, adding to the net carbon in the atmosphere.

Large-scale tree planting campaigns will be increasingly needed to replace trees and forests damaged or killed by severe weather events and more stressful climate conditions aggravated by climate change. Trees are also one of the best means to sequester large amounts of atmospheric carbon for long periods of time and can be planted on a massive scale.

References

1. US Department of Agriculture. Forests of Nebraska, 2015. [Internet]. 2015. Available from: https://www.fs.fed.us/nrs/pubs/ru/ru_fs75.pdf.
2. Wilhite D, Morrow K. The implications of climate change for Nebraska: summary report of sector-based roundtable discussions. [Internet]. 2015. School of Natural Resources, University of Nebraska. Available from: http://z.umn.edu/nebraska.
3. US Environmental Protection Agency. Climate change indicators: US and global temperature. [Internet]. 2016. Available from: http://z.umn.edu/neepa.

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What's Your Carbon Footprint?

The University of California at Berkeley has a carbon footprint calculator that helps estimate how much carbon dioxide and other greenhouse gases individuals use each year. Plug in information about your travel, home, shopping habits, food purchases, and more. By answering several questions in each of these categories, the calculator estimates your footprint, comparing it to the average footprint. Your total footprint can be compared with others in the US, relative to the state of your residence and household size.

To estimate your carbon footprint, visit: http://coolclimate.berkeley.edu/calculator.

Climate change presents major challenges to the health and quality of life of Midwesterners.

Midwest Climate Changes and Its Impacts on Health

by Kristin K. Raab, MPH, MLA

Although the Midwest does not experience some of the more publicized climate effects, such as sea level rise, the Midwest is not immune to climate change. In fact, the Midwest is experiencing disturbing climate changes that impact people's health. Two of the most important observed climate changes are rising air temperatures and more severe precipitation events. Increasing average annual temperatures and heavy precipitation events are altering our weather patterns, air quality, water cycles, and ecosystems, and these, in turn, are causing tangible changes in "climate hazards," including air pollution, extreme heat events, flooding, drought, and ecosystem threats, all of which are associated with a wide range of health impacts.[1]

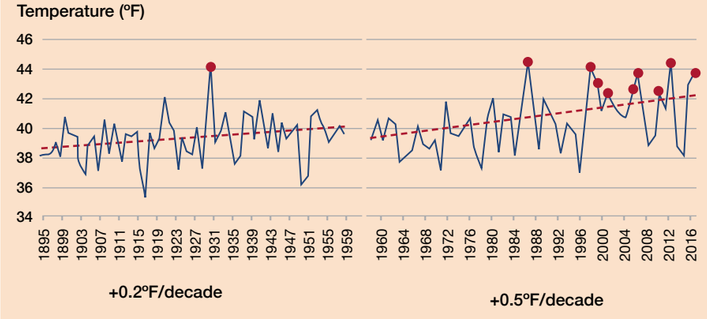
Rising Temperatures

From 1900 to 2010, the average Midwest air temperature increased by more than 1.5° F; however, the rate of warming in the Midwest has accelerated over the past few decades. Using Minnesota as an example, data collected by the National Oceanic Atmospheric Administration show that Minnesota's average annual air temperature was 39.3°F in the early 1900s (1990-1910). Currently the average is 41.9°F (2006-2016).[2] Similar to the rest of the Midwest, the pace of warming has hastened. From 1895 to 1959, annual average air temperatures in Minnesota increased at a rate of about 0.2°F per decade. In comparison, the rate of increase between 1960 and 2016 rose to a staggering 0.5°F per decade (Figure 1).[2]

Increases in Extreme Precipitation

Extreme rain events are another disturbing trend in the Midwest. The annual frequency of storms with precipitation of three inches or greater increased by 103% from

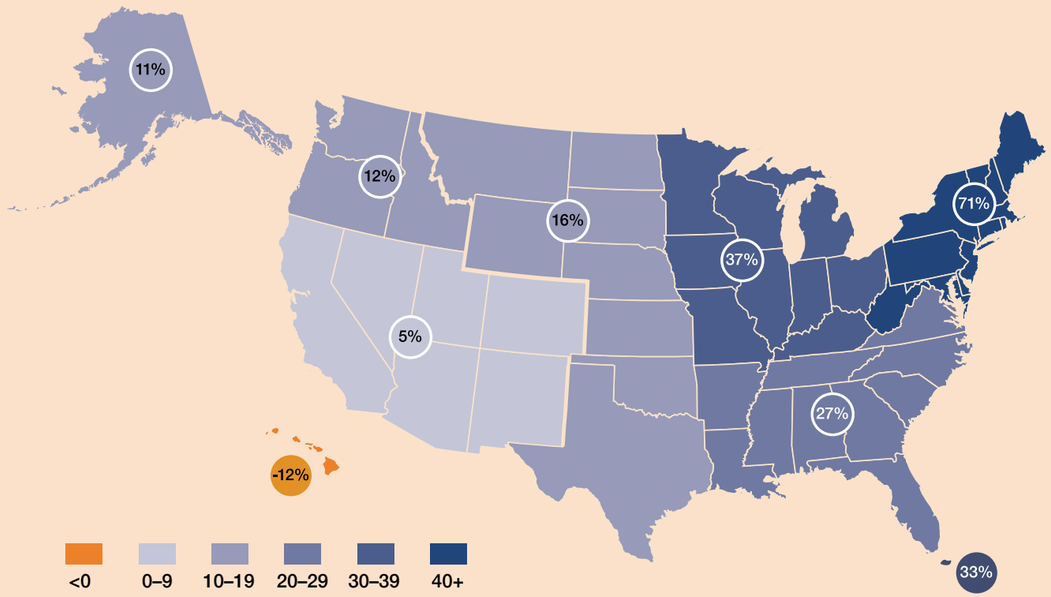
Figure 1: Minnesota Average Annual Temperature, 1895–2016



The most recent data suggest that increasing temperatures are becoming the norm. In 2016, the Midwest region hit its 4th warmest year on record since 1895, and the individual states' average temperatures ranked between 3rd to 6th warmest. The 2016 fall season tied 1931 for the warmest in recorded history for the Midwest (+5.2°F).[3] An examination of Minnesota's temperature record from 1895 to 2016 demonstrates that nine of the 10 warmest years in Minnesota have occurred within the last three decades.[2]

Source: National Oceanic and Atmospheric Administration (NOAA). NOAA National Centers for Environmental Information, Climate at a Glance: U.S. Time Series, Average Temperature, 2017. Available at http://www.ncdc.noaa.gov/cag/. Data amended by the Minnesota Department of Health, MN Climate & Health Program Environmental Health Division.

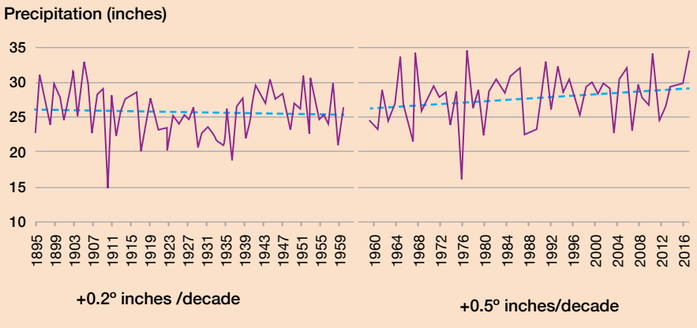
Figure 2: Observed Change in Very Heavy Precipitation



The map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawai'i, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012.

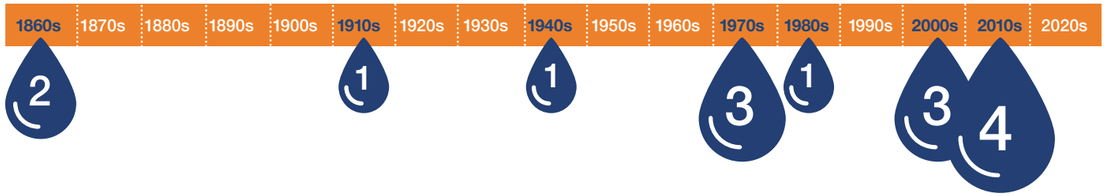
Source: U.S. Global Change Research Program (USGCRP), Climate Change Impacts in the United States: The Third National Climate Assessment report, Chapter 2. 2014. Updated from Karl et al. 2009. Figure available at https://data.globalchange.gov/file/bb534afa-cb2e-4b41-9cf7-03643340d321. Report available at https://data.globalchange.gov/report/nca2.

Figure 3: Minnesota Average Annual Precipitation, 1895–2016



Source: National Oceanic and Atmospheric Administration (NOAA). NOAA National Centers for Environmental Information, Climate at a Glance: U.S. Time Series, Precipitation, 2017. Available from: http://www.ncdc.noaa.gov/cag/. Data amended by the Minnesota Department of Health, MN Climate & Health Program, Environmental Health Division.

Figure 4: Number of Minnesota Mega-Rain Events by Decade



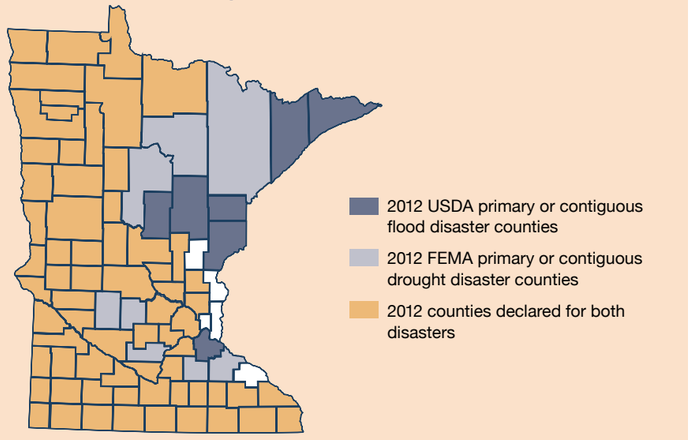
Source: Minnesota Department of Health, 2016. Data from the Minnesota Department of Natural Resources, 2016.

1961 through 2011. For storms of at least two inches, but less than three inches in a day, the increase was 81%.[4] Additionally, the heaviest 1% of all daily events from 1958-2012 has increased by 37% in the Midwest (Figure 2).[5] Using Minnesota again as an example, from 1895-1959, the trend in precipitation was slightly downward, at a loss of 0.2 inches per decade, influenced by the Dust Bowl years of the 1930s. However, from 1960-2016, the rate of precipitation across the state increased by nearly 0.5 inches per decade (Figure 3). The increase in precipitation over the last half a century has been driven primarily by heavier rainfall events.

One rainfall event of concern is referred to as a "mega" rain event: six inches of rain that cover more than 1000 square miles and the core of the storm that exceeds eight inches. Since 1866, 15 mega rain events have been documented in Minnesota, with ten occurring since 1970. In 2016, Minnesota, for the first year in its history, recorded two mega-rains in one year (Figure 4).[6] The Midwest is predicted to continue to receive more precipitation, and more precipitation from larger storm events.[7]

More precipitation doesn't necessarily mean an equal distribution of rain across the state. Minnesota, like the rest of the Midwest, is starting to experience increases in localized, heavy precipitation events, which have the potential to cause both increased flooding and drought. The localized nature of storms and their intensity are leaving some areas of Minnesota drenched while other areas receive no

Figure 5: How Do We Prepare for Precipitation Extremes?



Source: Minnesota Department of Health (MDH). Minnesota Climate & Health Profile Report. 2015, p 23. Available at http://www.health.state.mn.us/divs/climatechange/docs/mnprofile2015.pdf. (Data originally from USDA, 2012 and FEMA, 2012).

precipitation. As an example, in 2012, 75 Minnesota counties were declared primary or contiguous disaster areas for drought (Figure 5). That same year, 15 counties and three tribal reservations were declared disaster areas for flooding, with eight counties receiving disaster designation for both, underscoring the intensification of precipitation extremes in both directions.[1]

Public Health Impacts of Climate Change

A rise in greenhouse gases in our atmosphere is increasing air temperatures and changing the character of precipitation. These changes are leading to shifts in air quality, weather patterns, water cycles and ecosystems, which are affecting several "climate hazards," including air pollution, extreme heat, flooding, drought, and ecosystem threats (Figure 6). All of these

"climate hazards" increase people's risk of suffering from negative health impacts.

One area of concern related to air pollution is allergenic pollen. Warmer weather from increasing air temperatures changes the first and last frost dates and extends the freeze-free season, which lengthens the growing season. In Minneapolis-St. Paul, the length of the freeze-free season increased 16 days from 1951-2012.[8] A longer growing season may benefit certain agricultural crops, but it also benefits allergenic plants. From 1995 to 2015, Minneapolis experienced an 18-day increase in the length of the ragweed season.[9] Consequently, people with allergies may be stressed for a longer period of time during the year.

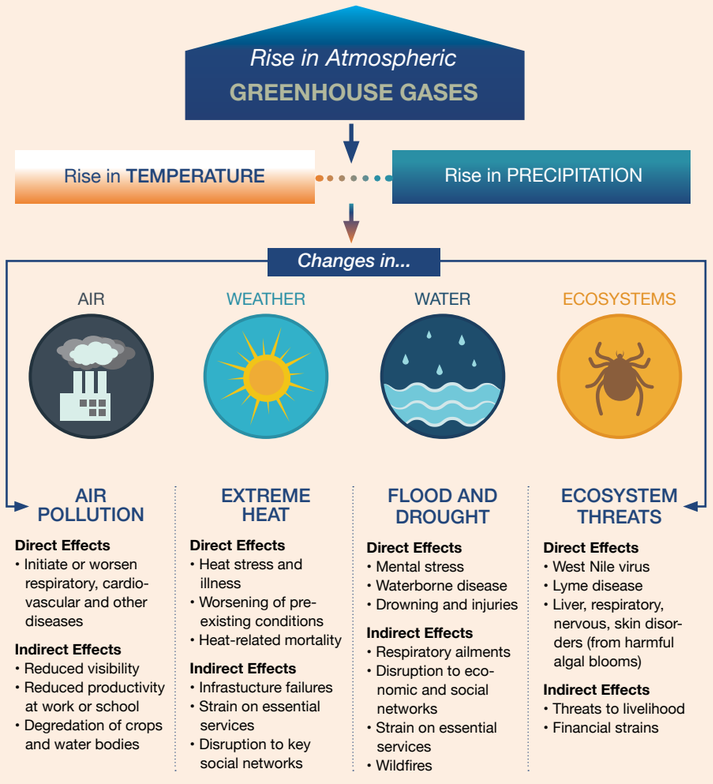
Increases in average temperatures are predicted to increase extreme heat events.[10] Heat waves directly affect health by causing heat exhaustion, heat stroke, and even death. During the summer of 2011, the heat index in the Twin Cities reached 105°F or greater on six days. That same summer there were 1,255 emergency department visits and three deaths directly related to heat.[11] Heat can also exacerbate morbidity and mortality associated with cardiovascular,[12] respiratory,[12] endocrine, [12,13] genitourinary,[12,13] renal,[13] and other conditions.[12,13]

Heavy precipitation can lead to flooding. From 2000 to 2015, flash and river flooding caused 16 deaths in Minnesota.[14] In addition to direct injuries or deaths from exposure to flood waters, flooding can also lead to respiratory problems arising from mold growth in wet basements, mental health problems triggered by injuries or property loss, and disease outbreaks from contaminated drinking water. As previously noted, precipitation is not evenly distributed in the Midwest (and elsewhere). Insufficient rain is also a concern: drought can potentially reduce drinking water supply, increase the likelihood of wildfires, and cause fiscal strain for those in agriculture or other water-dependent industries.

NOAA Climate Summaries Available for Every State

The National Oceanic and Atmospheric Administration (NOAA), US Department of Commerce (http://www.noaa.gov) is a great national source of climate data. It produces state-level summaries about observed climate change. The summaries also project major trends in the next 25-100 years. Each state summary consists of descriptions of the historical climate conditions in the state and the climate conditions associated with future pathways of greenhouse gas emissions. Individual state summaries are available at https://statesummaries.ncics.org.

Figure 6: Changes in Our Atmosphere Lead to Health Effects



Source: Minnesota Department of Health, MN Climate & Health Program, Environmental Health Division.

Higher temperatures have been linked to an earlier emergence of blacklegged ticks and their spread to new geographical areas.[16] Blacklegged ticks carry the pathogens that cause Lyme disease, human anaplasmois, and babesiosis.

Climate change is also affecting Midwest ecosystems and habitat. Warmer and wetter summers may lead to more cases of tick-borne diseases. Although many factors influence a person's risk of developing a vector-borne disease, climate is an important variable.[15] Higher temperatures have been linked to an earlier emergence of blacklegged ticks and their spread to new geographical areas.[16] Blacklegged ticks carry the pathogens that cause Lyme disease, human anaplasmois, and babesiosis. The number of reported cases of Lyme disease is increasing. In Minnesota, the median number of Lyme disease cases from 2006 through 2015 was 1,121, significantly more than the median from 1996 to 2005 of 464 cases.[17]

This article provided a very brief overview of the climate changes occurring in the Midwest and some of the corresponding health impacts. Poor air quality, extreme heat, flooding, drought, and ecosystem threats are already befalling the Midwest. Unfortunately, these climate hazards are expected to continue, occurring more often and with greater magnitude in the future. Climate change presents major challenges to the health and quality of life of Midwesterners. Acting now to adapt to the effects of climate change and significantly cutting greenhouse gases is paramount. Indeed, our future health depends on it!

References

1. Minnesota Department of Health, MN Climate and Health Program, Environmental Impacts Analysis Unit. Minnesota climate and health profile. [Internet]. 2015. Available from: http://www.health.state.mn.us/divs/climatechange/docs/mnprofile2015.pdf.
2. National Oceanic and Atmospheric Administration (NOAA). NOAA National Centers for Environmental Information, Climate at a glance: US time series, average temperature. [Internet]. 2017. Available from: http://www.ncdc.noaa.gov/cag.
3. Midwestern Regional Climate Center. Climate observer. [Internet]. 2017. Available from: http://mrcc.isws.illinois.edu/cliwatch/eNews/observer_201701_full.html.
4. Rocky Mountain Climate Organization and the Natural Resources Defense Council. Double trouble: more midwestern extreme storms. [Internet]. 2012. Available from: http://www.rockymountainclimate.org/images/Doubled%20Trouble.pdf.
5. US Global Change Research Program. Observed change in very heavy precipitation. [Internet]. 2013. Available from: https://data.globalchange.gov/report/nca3/chapter/our-changing-climate/figure/observed-change-in-very-heavy-precipitation-2.
6. Minnesota Department of Natural Resources. Historic mega-rain events in Minnesota. [Internet]. Available from: http://www.dnr.state.mn.us/climate/summaries_and_publications/mega_rain_events.html.
7. US Global Change Research Program. National climate assessment. Midwest. [Internet]. 2014. Available from: http://nca2014.globalchange.gov/report/regions/midwest#graphic-17083.
8. Great Lakes Integrated Sciences + Assessments (GLISA). Historical climatology: Minneapolis-Saint Paul, Minnesota. [Internet]. Available from: http://glisa.umich.edu/media/files/Minn-StPaulMN_Climatology.pdf.
9. Environmental Protection Agency. Climate change indicators in the United States: ragweed pollen season. [Internet]. 2016. Available from: https://www.epa.gov/sites/production/files/2016-08/documents/print_ragweed-2016.pdf.
10. Anderson GB, Bell ML. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 US Communities. Environ Health Perspect 2011; 119(2):210-8.
11. Minnesota Department of Health. Heat-related illnesses. Emergency Department visits: facts & figures. [Internet]. Available from: https://apps.health.state.mn.us/mndata/heat_ed.
12. Bunker A, Wildenhain J, Vandenbergh A, et al. Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly: a systematic review and meta-analysis of epidemiological evidence. EBioMedicine 2016; 6:258-68.
13. Li B, Sain S, Mearns LO, et al. The impact of extreme heat on morbidity in Milwaukee, Wisconsin. Climatic Change 2012;110(3-4):959-76.
14. National Weather Service, Office of Climate, Water, and Weather Services. Natural hazard statistics: weather fatalities. [Internet]. 2015. Available from: http://www.nws.noaa.gov/os/hazstats.shtml.
15. Minnesota Department of Health, Infectious Disease Epidemiology, Prevention and Control Division. Vector-borne diseases and climate change. [Internet]. 2015. Available from: www.health.state.mn.us/divs/idepc/dtopics/vectorborne/climate.html.
16. Levi T, Keesing F, Oggenfuss K, et al. Accelerated phenology of blacklegged ticks under climate warming. Philos Trans R Soc London B Biol Sci 2015;370(1665). Available from: http://rstb.royalsocietypublishing.org/content/370/1665/20130556.
17. Minnesota Department of Health. Lyme disease statistics. [Internet]. 2016. Available from: http://www.health.state.mn.us/divs/idepc/diseases/lyme/statistics.html.

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Vulnerability to Climate-change Related Health Effects

by Wendy L. Hellerstedt, MPH, PhD

The effects of severe weather and climate on human health are significant and varied.[1] One gauge of the potential effect of climate change on health is data about natural disasters. In 2015, there was a total of 574 natural disasters caused by earthquakes, floods, droughts, landslides and heat waves.[2] They killed almost 32,550 people, affected over 108 million people, and caused $70.3 billion in damage.[2]

The number of disasters continues to rise, as a result of a combination of increased vulnerability (e.g., more people living in dangerous places, aging infrastructures) and climate change-related extreme weather. 2015 was the second hottest year on record (2016 was the hottest) with 32 major droughts, double the 10-year average.[2]

Lone Bird*

Some scientists have asserted that climate change poses a "catastrophic risk" that could undermine the global health gains of the past half century.

Another gauge of the effects of climate change on health comes from the World Health Organization (WHO) which estimated that, in 2012, 12.6 million deaths (23% of deaths worldwide) were attributable to environmental factors, many of which were directly or indirectly related to climate change.[3]

WHO also examined another measure of health—DALYs (disability adjusted life years)—to assess the health consequences of climate change. WHO considered four major consequences of climate change (food-and water-borne diseases, vector-borne diseases, natural disasters, and risk of malnutrition) and estimated that climate change was responsible for more than 5.5 million DALYs lost in 2000.[4] Given the increase in climate change and subsequent effects since 2000, that figure is likely much higher almost two decades later.

The WHO provided the following list (printed below verbatim)[4] of several consequences of climate change for which the impact on health is difficult or impossible to quantify:

- Changes in air pollution and aero-allergen levels;
- Altered transmission of infectious diseases;
- Effects on food production via climatic influences on plant pests and diseases;
- Drought and famine;
- Population displacement due to natural disasters, crop failure, water shortages, etc.;
- Destruction of health infrastructure in natural disasters;
- Conflict over natural resources; and
- Direct impacts of heat and cold.

The difficulty in quantifying the health consequences of climate change was reinforced in the most recent (2014) International Panel of Climate Change (IPCC) report, which nonetheless concluded that the health effects were varied; likely to continue unless there are extraordinary mitigation, adaptation, and resilience efforts; and will continue to disproportionately affect both individuals in low- and middle-income countries and those who are socially vulnerable in every country.[5] Despite the difficulty in quantifying risks, many scientists and health professionals agree that climate change is the world's most important public health threat.[1,4-14] Some scientists have asserted that climate change poses a "catastrophic risk" that could undermine the global health gains of the past half century.[5,9] (For more information on climate change-specific health effects, read articles in this volume by Hellerstedt on page 26, Raab on page 17, Dorr on page 34, and Toscano and Sehgal on page 37).

Conceptualizing the Health Impact of Climate Change

There are many considerations when conceptualizing the complex associations of climate change and human health. Among the inter-related considerations are that:

- Climate change has direct and indirect effects;
- Climate change interacts with other conditions to produce risk; and
- Individuals have different vulnerabilities to climate change.

Direct and Indirect Effects. The direct impacts of climate change result from rising temperatures and extreme weather events, like droughts, storms and floods. The indirect effects are varied and include social and economic consequences (e.g., disruptions in labor, civil unrest, or migration following events like drought or crop failures), secondary responses to direct effects (e.g., offspring stunting related to prenatal malnutrition related to climate-affected food insecurity), and long-term emotional responses (e.g., post-traumatic stress following extreme weather events). Some of the indirect effects can be significantly delayed, such as chronic disease

Hungry Child**

Climate Change Will Create Extreme Poverty for Millions

Poverty not only increases vulnerability to climate change, but climate change itself can increase the number of impoverished people.

In 2015, the World Bank released a working paper asserting that climate change could push more than 100 million people into extreme poverty by 2030. The estimates were based, in part, on surveys of 1.4 million people in 92 low- and middle-income countries. Respondents were asked why they fell—or could fall—into poverty. They cited three major factors: agricultural shocks (including an increase in food prices), natural disasters (e.g., floods, extreme weather, droughts), and health issues (e.g., malaria, diarrheal diseases). Climate change is strongly related to all three. For example, the report referred to studies that projected that climate change could result in global crop yield losses as large as 5% by 2030 and 30% by 2080. It also cited research showing that warming temperatures could increase the number of people at risk for malaria by 150 million. The report stated that the people most at risk extreme poverty due to climate change were already poor people in sub-Saharan Africa and South Asia.

In 2014, a World Bank report, *Turn Down the Heat,* provided a comprehensive review of climate change effects globally, with an emphasis on social determinants of health. In that report, it emphasized that climate change threatened to erode the progress made on reducing poverty globally. One of the reasons cited in the report is that climate change has resulted—and will continue to result—in massive migration patterns. It has, in effect, created millions of "climate refugees" who lost their livelihoods and thus left their homes, family, and friends to seek shelter and work elsewhere.

As described in a recent commentary from *Ensia*, because of the impact of climate change on poverty and migration, leaders working on development issues in low-income countries are calling for more resources to support climate adaptation (e.g., improving water and food security, modernizing infrastructure).

For More Information

- The 2015 World Bank working paper is available from: http://documents.worldbank.org/curated/en/349001468197334987/pdf/WPS7483.pdf.
- World Bank's *Turn Down the Heat* is available from: https://openknowledge.worldbank.org/handle/10986/20595.
- The Ensia commentary is available from: https://ensia.com/voices/climate-change-disproportionately-hits-worlds-poorest.

risks associated with earlier exposure to a toxin or an infectious disease agent.

Interactions with Other Risk Factors. The health effects of climate change will be modified by factors such as the socioeconomic development of a community or the degree in which the community has engaged in mitigation and adaptation activities. [1,3,6-10,12-16] Even though most studies assess the effects of climate change in isolation from other environmental risks, direct climate change consequences are likely to be experienced in the context of other factors that can affect health, such as overpopulation, urban density, over-extended medical and public health infrastructures, pollution, and depletion of water resources.[8] Further, it is possible for people to be exposed to multiple climate change threats simultaneously, "…resulting in compounding or cascading health impacts." [11]

Variation in Vulnerability. The IPCC stated that, "Differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes. These differences shape differential risks from climate change."[5] The IPCC also stated that climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty. Not only can climate change effects negatively influence socioeconomic circumstances, but social conditions themselves (e.g., violent conflict) can increase vulnerability to climate change. [5]

It is hypothesized, by the IPCC and other scientists,[1,5-11,13,16] that climate change has had (and will have for at least 2-3 more decades) the most profound impact on people with existing health problems (e.g., malnourished individuals may be more severely affected by vector-borne diseases; mentally ill individuals may be most affected by climate-induced stress) or other vulnerabilities, such as extreme age (e.g., the elderly and children may be least able to combat extreme heat or escape from extreme weather events). It is generally agreed that people in low-and middle-income countries—and low-income people in any country—are the least able to combat the effects of climate change, including severe weather events.

In addition to individual vulnerabilities, there are also geographic vulnerabilities. "Areas already experiencing health-threatening weather are most likely to be hardest hit initially, experiencing worsening impacts, such as higher temperatures and increased storm intensity, rainfall rates, and storm surge, or a shift in when these threats occur."[11] Ultimately, all areas of the world will experience new climate-related threats and vulnerability will expand to more privileged individuals and communities as the magnitude of climate-related problems expands.

Conclusions

As stated by the IPCC, the most effective measures to reduce vulnerability to climate change-related health consequences are to implement basic public health measures that assure the availability of clean water, a safe and nutritious food supply, sanitation, essential health care (including immunizations and child health services), and a workforce that has the capacity for risk assessment and management, health impact assessment, and emergency preparedness (e.g., early warning systems for extreme weather events).[5]

It is also important that the public receives evidence-based education about how to protect themselves from extreme weather events. Many such public information materials exist, like the Centers for Disease Control and Prevention's *Extreme Heat Guide.*[17] The public also needs positively oriented education about how reducing fossil fuel use can have positive co-benefits beyond the climate.[1,12] For example, education could encourage individuals in high-consumption societies to reduce intake of animal products, stressing that such action would both reduce climate-altering pollutants and reduce their risks for nutrition-related conditions, like cardiovascular disease and some cancers.

In addition to actions beyond the individual and the public health sector, larger societal efforts to reduce poverty and promote social equality (and thus decrease economic vulnerability), build green cities and energy-efficient buildings, protect workers who are exposed to high-heat situations, and promote the widespread use of clean energy (e.g., through business regulation and taxation) would also decrease exposure to climate-related health effects and/or reduce vulnerability to them. [5,9,16]

References

1. Patz JA, Frumkin H, Holloway T, et al. Climate change: challenges and opportunities for global health. JAMA 2014;312(15):1565-80. Available from: http://jamanetwork.com/journals/jama/fullarticle/1909928.
2. International Federation of Red Cross and Red Crescent Societies. World disasters report 2016. [Internet]. 2017. Available from: http://www.ifrc.org/Global/Documents/Secretariat/201610/WDR%202016-FINAL_web.pdf.
3. Neira M. Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. World Health Organization. 2016. Available from: http://www.who.int/quantifying_ehimpacts/publications/preventing-disease/en/.
4. Campbell-Lendrum DH, Corvalán CF, Prüss Ustün A. How much disease could climate change cause? In: McMichael AJ, Campbell-Lendrum DH, Corvalan CF, et al. (Eds). Climate change and human health: risks and responses. Geneva: WHO. 2003. Available from: http://www.who.int/globalchange/summary/en/index6.html3.
5. Smith KR, Woodward A, Campbell-Lendrum D, et al. Human health: impacts, adaptation, and co-benefits. In: Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change [Field CB, Barros VR, Dokken DJ, et al. (Eds.)]. Cambridge and New York: Cambridge University Press. 2014. Available from: https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap11_FINAL.pdf.
6. Costello A, Abbas M, Allen A, et al. Managing the health effects of climate change. Lancet 2009;373(9676):1693-733. Available from: http://z.umn.edu/costello.
7. Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet 2015;386(10007):1973-2028. Available from: https://www.rockefellerfoundation.org/report/safeguarding-human-health-anthropocene-epoch/.
8. Haines A, Kovats RS, Campbell-Lendrum D, et al. Climate change and human health: impacts, vulnerability and public health. Public Health 2006;120(7):585-96. Available from: https://pdfs.semanticscholar.org/c237/332fd97e96f79218927747557598b93b429.pdf.
9. Watts N, Adger N, Agnolucci P, et al. Health and climate change: policy responses to protect public health. Lancet 2015;386:1861-914.
10. Watts N, Adger WN, Ayeb-Karlsson S, et al. The Lancet Countdown: tracking progress on health and climate change. Lancet. 2016;389:1151-64. Available from: https://collections.unu.edu/eserv/UNU:5861/Lancet_Countdown_Final_paper.pdf.
11. US Global Change Research Program. National climate assessment. [Internet]. 2014. Available from: http://nca2014.globalchange.gov/.
12. Frumkin H, Hess J, Luber G, et al. Climate change: the public health response. Am J Public Health;2008:98(3):435-45. Available from: http://z.umn.edu/frumkin.
13. Brown H, Spickett J, Katscherian D. A health impact assessment framework for assessing vulnerability and adaptation planning for climate change. Int J Environ Research Public Health 2014;11(12):12896-914. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4276652/.
14. Levy B, Patz J. Climate change and public health. New York: Oxford University Press. 2015.
15. Huber DG, Gulledge J. Extreme weather and climate change: understanding the link and managing the risks. Center for Climate and Energy Solutions. [Internet]. 2011. Available from: https://www.c2es.org/publications/extreme-weather-and-climate-change.
16. Intergovernmental Panel on Climate Change. Working Group III. Climate change fifth assessment report. Mitigation of climate change. [Internet]. 2014. Available from: https://www.ipcc.ch/report/ar5/wg3/.
17. Centers for Disease Control and Prevention. Extreme heat guide. [Internet]. Available from: https://www.epa.gov/climatechange/extreme-heat-guidebook.

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Minnesota Climate and Health Information, Planning, and Education Materials at Your Fingertips!

The Minnesota Department of Health's Minnesota Climate and Health Program website, at www.health.mn.gov/climatechange, provides information, tools, and resources about the health impacts of our changing climate to help build more resilient communities. The content is frequently updated to reflect the latest science and is often relevant for public health and other professionals beyond Minnesota. Its comprehensive scope of information includes:

- **Descriptions of Climate Change Health Topics**—Review information about health as it relates to extreme heat events, water quality and quantity, air quality, vector-borne diseases, agriculture, and mental health.
- **Planning Tools and Data**—Download the latest reports about climate and health in Minnesota.
- **Communication and Training Materials**—Access "train the trainer" modules, scripted for educational purposes. There are materials for a variety of audiences, from schoolchildren to adults. For example, view the *Health and Climate* video (and study guide) at www.health.mn.gov/climatechange/climatevideo.html.

Visit the Minnesota Climate and Health Program website today and sign up to receive e-mail updates from the program to stay informed!

What's Bad for the Planet is Bad for People:
the Health Consequences of Climate Change

by Wendy L. Hellerstedt, MPH, PhD

The health effects of climate change are projected to become more severe in the future[1] and may undermine the gains in public health and development that have been made over the past half century.[2] The health risks are unevenly distributed. Climate change has the potential to be an enormous contributor to health inequality and health disparities.

Individuals in low- and middle-income countries are at much higher risk than those in high-income countries.[3-13] This is true for several reasons: people in low- and middle-income countries are most likely to live in high-risk areas, like flood plains and coastal zones. They are also most likely to live where public health and medical infrastructures are weak and to be exposed to economies that could be devastated by extreme weather events.[8] Climate change is, in fact, an impediment to future health improvements, especially in low-income countries.[5] And, in every country, the poor, those who lack health insurance or health care, the sick, the aged, and the very young are at highest risk.[4-7,10,12,13]

Climate change can affect human health in two major ways:[1]

- Changing the severity or frequency of existing health problems; and
- Creating new health problems for individuals—or new health threats in places where they have not previously occurred.

While quantifying some specific climate change-related health risks is difficult,[5] scientists generally agree with the assertion by *Lancet* scholars that climate change is "…the biggest global health threat of the 21st Century."[6,10] The World Health Organization estimated that "…climate change will cause an additional 250,000 deaths per year from 2030 to 2050…" These deaths will be due primarily to diarrhea, malaria, and heat exposure.[15]

Heat-related Health Risks

Heat-related health risks associated with climate change are those for which there is probably the most scientific agreement.[5] Increasing concentrations of greenhouse gases lead to an increase in both average and extreme temperatures.

"Loss of internal temperature control can result in many illnesses, including heat cramps, heat exhaustion, heatstroke, and hyperthermia in the presence of extreme heat," according to the US Global Change Research Program.[1] "Temperature extremes can also worsen chronic conditions such as cardiovascular disease, respiratory disease, cerebrovascular disease, and diabetes-related conditions. Prolonged exposure to high temperatures is associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders."[1] Heat can also be associated with gastrointestinal disorders in children (possibly from eating contaminated food or swimming in contaminated water) and neuropsychiatric disorders.[16]

A study that examined climate models of average daily temperatures in Manhattan from 1985-2010 and birth certificate data for the same period concluded that

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exposures to an extra day where average temperature were >85 °F during pregnancy was associated with modest reductions (1.8 gm) in birth weight. The impact varied by maternal economic status; adolescent mothers were especially vulnerable.[17]

The Earth has already experienced devastating heat events in the 21st Century. For example, it is estimated that the 2003 European heat wave was responsible for 70,000 deaths[18] and the 2010 Russian heat wave caused 15,000 deaths.[19] Mega-heat waves are projected to increase 5-10-fold in the next 40 years.[20] There could thus be an increase of thousands—maybe tens of thousands—of premature heat-related deaths as a result of climate change each year by the end of the 21st Century.[1,5] The reduction in cold-related deaths is projected to be smaller than the increase in heat-related deaths in most regions.[1]

The very old, the very young, and the sick are particularly vulnerable to thermal stress because they have limited ability to thermo-regulate. In addition, children and low-income people are generally less able to relocate away from a difficult climate, especially if a heat wave is sudden and severe. In children, heat stroke is the most serious outcome of central or peripheral impairment of body temperature regulation and may result in death.[16]

Residents of urban areas with many dry, paved surfaces are at risk because of "heat islands" that cause urban areas to be hotter than surrounding ex-urban areas. The annual mean air temperature of a city with one million people or more can be 1.8–5.4°F warmer than its surroundings. In the evening, the difference can be as high as 22°F.[21] And certain occupational workers—especially those who work outdoors—are also at special risk.[16] It is projected that by 2050, workdays lost because of heat could reach 15-18% in South East Asia, West and Central Africa, and Central America.[22]

There are several preventive measures against heat-related illnesses, but some (like air conditioning) could mean increased energy use. Other measures, including those described by Moran on page 55, include:

- Establishing heat-warning systems to alert people about imminent heat waves;[16]
- Making cool environments available (e.g., shading residences);[16]
- Educating the public about warning signs of heat stress;[16]
- Providing adequate ventilation in buildings;[16]
- Mitigating heat island effects through green building practices, development of urban gardens and forests, etc.;[21]
- Implementing worksite regulations to protect workers from over-exposure to heat; and
- Using building materials (e.g., light colors) that reduce heat build-up.[16]

Climate Change is a Threat Multiplier for Vulnerable Populations

Climate change is widely considered a "threat multiplier" relative to its potential to negatively affect already vulnerable populations, communities, and entire societies. A key message from the US Third National Climate Assessment is that, "*Vulnerability to climate change is exacerbated by other stresses such as pollution, habitat fragmentation, and poverty. Adaptation to multiple stresses requires assessment of the composite threats as well as tradeoffs amongst costs, benefits, and risks of available options.*" (http://nca2014.globalchange.gov).

According to a 2014 US Pentagon report, "*The impacts of climate change may cause instability in other countries by impairing access to food and water, damaging infrastructure, spreading disease, uprooting and displacing large numbers of people, compelling mass migration, interrupting commercial activity, or restricting electricity availability…These developments could undermine already-fragile governments that are unable to respond effectively or challenge currently-stable governments, as well as increasing competition and tension between countries vying for limited resources. These gaps in governance can create an avenue for extremist ideologies and conditions that foster terrorism.*" (http://z.umn.edu/pentagon).

Documentation of the potential effects of climate change on socially vulnerable populations is provided by many sources, including:

- **The Intergovernmental Panel on Climate Change (IPCC)**, which reported that, by 2100, climate change will increase the number of poor people in both developed and developing countries, jeopardizing sustainable development. It will worsen existing poverty, exacerbate inequalities, and create new vulnerabilities. *"Climate change interacts with non-climatic stressors and entrenched structural inequalities to shape vulnerabilities,"* as stated in IPCC's chapter on livelihoods, poverty, and climate change. (https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/drafts/fd/WGIIAR5-Chap13_FGDall.pdf).
- **The World Bank Group**, which asserted that climate change could force more than 100 million people into extreme poverty by 2030 and could threaten global efforts to combat poverty. Climate change solutions must address the specific needs of the poor, according to its report, *Shock Waves: Managing the Impacts of Climate Change on Poverty.* (https://openknowledge.worldbank.org/bitstream/handle/10986/22787/9781464806735.pdf).

Extreme Weather Events

In addition to heat waves, other extreme weather events that will increase in frequency, duration, and intensity because of climate change include droughts, wildfires, and flooding related to extreme precipitation and hurricanes. For example, climate change will increase exposure risk to coastal flooding because of increases in extreme precipitation, hurricane intensity and rainfall rates. Climate-related sea level rise will increase the frequency and intensity of storms.

Extreme weather events can cause death and injury during an event (for example, drowning during floods), but health consequences can also occur before or after an extreme event (e.g., individuals may be involved in activities that put their health at risk, such as disaster preparation and post-event cleanup).[1,5]

According to the US Global Change Research Program, "Health risks may… arise long after the event, or in places outside the area where the event took place, as a result of damage to property, destruction of assets, loss of infrastructure and public services, social and economic impacts, environmental degradation, and other factors. Extreme events also pose unique health risks if multiple events occur simultaneously or in succession in a given location. The severity and extent of health effects associated with extreme events depend on the physical impacts of the extreme events themselves as well as the unique human, societal, and environmental circumstances at the time and place where events occur."[1] For example, after floods, there are increases in diarrheal and respiratory diseases, even in high-income countries.[23] Droughts also have wide-ranging long-term effects on nutrition and infectious disease risks.[4,5,8,14] Similarly, wildfires (sometimes caused by excessive heat) are associated with air pollution that could result in acute or long-term effects (e.g., asthma, exacerbation of existing conditions).[8]

Some extreme events can severely disrupt infrastructures (e.g., utilities, transportation, communication) that are critical to accessing health care and emergency services.[1] Extreme weather events, in fact, are more likely to cause disruption than death. For example, in 1997 river flooding in central Europe left over 200,000 people homeless and 100 dead.[23] Hurricane Katrina—the most expensive natural disaster in US history—left perhaps 1,800 people dead and one million people displaced.[24]

Individuals at highest risk for extreme weather events include those living in high-risk areas (coastal areas, flood plains), people with disabilities or other access and functional needs, older adults, low-income people, and some occupational groups.[1,8]

Table 1. Vector-borne Diseases That are Likely to be Sensitive to Climate Change

Vector	Major Diseases
Mosquito	Malaria, dengue fever, yellow fever, West Nile fever
Sandflies	Leishmaniasis
Triatomines	Chagas disease
Ixodes ticks	Lyme disease and tick-borne encephalitis
Tsetse flies	African trypanosomiasis
Blackflies	Onchocerciasis
Snails (intermediate host)	Schistosomiasis

Source: Table adapted from Table 2, Haines et al.[8]

Vector-borne Diseases (see article by Dorr on page 34)

Global warming is likely to change the pattern of vector-borne illness because insects (as well as hosts, like birds and rodents) respond quickly to changes in temperature and moisture by migrating and increasing numbers.[5] According to the US Global Change Research Program, "Vector-borne diseases are illnesses that are transmitted by *vectors*, which include mosquitoes, ticks, and fleas. These vectors can carry infective pathogens such as viruses, bacteria, and protozoa, which can be transferred from one host (carrier) to another. The seasonality, distribution, and prevalence of vector-borne diseases are influenced significantly by climate factors, primarily high and low temperature extremes and precipitation patterns… For example, ticks capable of carrying the bacteria that cause Lyme disease and other pathogens will show earlier seasonal activity and a generally northward expansion in response to increasing temperatures associated with climate change. Longer seasonal activity and expanding geographic range of these ticks will increase the risk of human exposure to ticks…Climate change is likely to have both short- and long-term effects on vector-borne disease transmission and infection patterns, affecting both seasonal risk and broad geographic changes in disease occurrence over decades."[1] In addition to a changing environment that facilitates transmission, vector-borne diseases may become more prevalent because more people have high levels of contact with others: more live in crowded urban centers and more have access to travel options that link infected individuals with uninfected populations.[25]

Haines and colleagues speculated that there are several vector-borne diseases especially sensitive to climate change (Table 1).[8] In the 21st Century, there have been many reports of increases in vector-borne diseases (e.g., West Nile Virus in North America and Europe, Japanese encephalitis virus in Asia, malaria in East Africa).[25]

Individuals living in poverty and in tropical countries are at high risk for vector-borne diseases.[25] Children are particularly susceptible to malaria, dengue fever, and various forms of encephalitis.[25]

There are challenges to prevention that include disagreements about the importance or feasibility of eradication and control. Eradication of some vectors may be possible, but is often very costly and strategically difficult.[25] Often there is continued re-introduction of vector-borne diseases (e.g., malaria in Sri Lanka). When eradication is not possible, management and control programs are faced with choices to perform preventive or reactive measures.[25] In either case, ramping up such measures requires good predictive models (impossible without good surveillance data), money, organization, a prepared workforce, and timely implementation.[25]

One in Four Annual Deaths Worldwide Due to Pollution

Pollution (air, water, soil) and climate change are closely related and it is difficult to disentangle their effects. They often have the same etiology (fossil fuels) and they interact with one another to negatively affect the health of ecosystems, humans, and other species. For example, the main sources of carbon dioxide (CO_2) emissions—the extraction and burning of fossil fuels—are not only key drivers of climate change, but also major sources of air pollutants. Further, many air pollutants also contribute to climate change by affecting the amount of incoming sunlight that is reflected or absorbed by the atmosphere, with some pollutants warming and others cooling the Earth. These short-lived climate-forcing pollutants include methane, black carbon, ground-level ozone, and sulfate aerosols. Each has significant effects on the climate: for example, black carbon and methane are among the top contributors to climate change after CO_2.

In 2016, the World Health Organization (WHO) reported that 12.6 million people die every year because they live or work in an unhealthy environment. That is one in four deaths globally that the WHO attributes to the chemicals and waste that we have put in the air, water, and soil since the end of World War II. Nearly two-thirds of environment-related deaths (8.2 million) are related to non-communicable diseases (e.g., heart disease and cancer) caused by environmental exposures. Deaths from infectious and diarrheal diseases account for one-third of these environment-related deaths. While every part of the world is affected by environmental health risks, the WHO concluded that low- and middle-income countries, especially those in Asia that are manufacturing hubs, are most affected.

The following is the WHO's breakdown of global environment-related annual deaths:

- Stroke: 2.5 million
- Ischemic heart disease: 2.3 million
- Unintentional injuries: 1.7 million
- Cancers: 1.7 million
- Chronic respiratory disease: 1.4 million
- Diarrheal disease: 846,000
- Respiratory infections: 567,000
- Neonatal deaths: 270,000
- Malaria: 259,000
- Intentional injuries: 246,000

The WHO report is at http://www.who.int/quantifying_ehimpacts/publications/preventing-disease/en.

Respiratory and Allergic Disorders

Changes in the climate affect the air we breathe, indoors and outdoors.[1,5,26] According to the US Global Change Research Program, "The changing climate has modified weather patterns, which in turn have influenced the levels and location of outdoor air pollutants such as ground-level ozone and fine particulate matter."[1]

Ozone is the primary component of smog in urban settings. Climate change will

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make it harder to reduce ground-level ozone pollution through regulation, as climate change conditions become increasingly conducive to forming ozone.[1] Ozone exposure is associated with death and morbidity due to respiratory disorders, asthma, hospital visits, lost school days, and acute respiratory symptoms.[1,5,26,27] One of the most harmful air pollutants for children with asthma is ozone.[26]

The World Health Organization estimated that exposure to fine particulate air pollution causes about 800,000 deaths and 6.4 million lost years of healthy life in the world's cities every year.[15] Exposures to fine particulate matter is worldwide, with perhaps 32% of global residents living in areas that exceed safe standards for exposure.[27] Exposure is highest in low-income countries (especially in Asia) that have little air pollution enforcement.[27]

Wildfires are often a consequence of high temperatures and drought related to climate change.[28] Wildfire-created particulate matter and ozone precursors have been associated with exacerbating asthma symptoms and other chronic respiratory diseases, leading to hospitalizations and even death.[26,28] A study on global mortality estimated that between 260,000-600,000 premature deaths per year were associated with pollution from forest fires (especially particulates).[28] Deaths were greatest in sub-Saharan Africa and Southeast Asia.[28]

Increasing carbon dioxide (CO_2) levels also promote the growth of plants that release airborne allergens (aeroallergens).[1,26] Higher pollen concentrations and longer pollen seasons can increase allergic sensitization, asthma episodes, hay fever, and allergic rhinitis.[1,26] These changes to outdoor air quality and aeroallergens also affect indoor air quality because both pollutants and aeroallergens infiltrate homes, schools, and other buildings.[1] Extreme weather events, like hurricanes and floods, are also associated with respiratory disorders caused by mold.[26]

Asthma and allergies account for much of the premature mortality and morbidity in children and adults. Asthma is the most common chronic disease in childhood and is especially prevalent in urban areas.[15,26] For example, in March 2017, a thunderstorm triggered a rash of asthma attacks in the city of Melbourne, Australia, resulting in six deaths and 8,500 people receiving hospital treatment.

Children may be the greatest victims of air pollution, according to a 2016 UNICEF report.[29] The report estimated that 300 million children live with "toxic" air pollution and that there are about 600,000 deaths/year to children younger than 5 years-old that are attributable to air pollution—nearly twice the under-5 death toll caused by malaria.[29] Further, air pollution also contributes to very high child morbidity (e.g., bronchitis, asthma, pneumonia).[29]

There are several responses that can help reduce the risk of climate-related respiratory disorders, including: reducing pollution, routine pollen measurements, better monitoring of air pollution and air quality, public health programs that raise public awareness about risks, and specific outreach to—and identification of—at-risk populations (ill people, the elderly, children).[26,29,30] Because children are especially vulnerable, in 2016 UNICEF called for improved child access to health care (especially immunizations and respiratory disease management) and minimization of child exposure to air pollution at schools and playgrounds.[29]

Water-related Illnesses

The impact of climate change on water is two-fold: it increases the risks for water-borne illnesses (although data are limited about this)[5] and results in water scarcity in some parts of the world, especially sub-Saharan Africa.[31]

Water-related illnesses associated with climate change include those caused by pathogens, such as bacteria, viruses, and protozoa.[1,5,31,32] According to the US Global Change Research Program, "Water-related illnesses are…caused by toxins produced by certain harmful algae and cyanobacteria and by chemicals introduced into the environment by human activities. Exposure occurs through ingestion, inhalation, or direct contact with contaminated drinking or recreational water and through consumption of contaminated fish and shellfish. Factors related to climate change—including temperature, precipitation and related runoff, hurricanes, and storm surge—affect the growth, survival, spread, and virulence or toxicity of agents (causes) of water-related illness."[1]

Drought and floods are both related to disease transmission.[1,5,14,31,32] For example, the West Nile virus may be transmitted in drought areas when birds and other vectors use water supplies used by humans and cholera may develop where lack of water leads to poor sanitation.[31] Water contamination can also occur when flooding overwhelms sewage systems and

livestock waste enters the human water supply.[31,32]

Increases in some extreme weather events and storm surges will also increase the risks that infrastructures for drinking water, wastewater, and storm water will fail either because of damage or because use exceeds system capacity, especially in areas with aging infrastructure. This, in turn, could result in increases in pathogens, chemicals, and algal toxins in recreational and shellfish harvesting waters and in drinking water where treatment barriers break down.[1]

A meta-analysis of 87 studies from around the world reported that, between 1910-2010, heavy rainfall and flooding were the most common extreme weather events leading to water-borne disease outbreaks.[32] For example, childhood gastrointestinal illnesses have recently been associated with heavy rainfall in Wisconsin.[33] It is difficult to gauge the magnitude of climate-related water-borne disease events because many disease outbreaks are never recognized.[31]

Preventive measures include integrated water resource management in communities, use of climate projection models to engineer water systems, adaptation measures to decrease the potential for pathogen contamination of water supplies, regular review of water and treatment plant operations, and assessment of changes in pathogen concentrations under various climate change scenarios.[30,31]

Food Insecurity and Food-borne Illnesses

A safe and nutritious food supply is a vital component of food security.[1,34] According to the US Global Change Research Program, "…climate change is very likely to affect global, regional, and local food security by disrupting food availability, decreasing access to food, and making [food] utilization more difficult."[34] Climate change has affected food security—and will continue to do so—through food contamination, reduced crop yields/increased losses, disruptions in food distribution, and decreased nutrient content.[1,3,5,10,31,35,36]

Current and anticipated changes in climate and the physical environment have consequences for contamination of the food supply.[1,31,35,36] For example, elevated sea surface temperatures will lead to greater accumulation of mercury in seafood, while increases in extreme weather events will introduce contaminants into the food chain.[1] Rising CO_2 concentrations will alter the incidence and distribution of pests, parasites, and microbes, leading to increases in the use of pesticides and veterinary drugs in food production.[1]

On average, climate change is estimated to decrease global food production by about 2% per decade—and, because of population growth, demand is expected to ***increase*** by 14% per decade.[5] One way that food production will decrease is through increases in plant diseases, which are already responsible for 16% of the world's crop losses.[35] Another way is through changes in crop and livestock environments because of drought, flooding, and increased salt-affected soils (as a result of rising sea levels that bring salt water further inland).

Globally, about 805 million people are chronically undernourished (and many of them are children).[34] Unfortunately, the areas where climate change may have its greatest effects (low-income countries) are also those where undernourishment is most prevalent.[34] As summarized by Patz and colleagues, climate change is projected to decrease wheat, maize, sorghum, and millet yields by about 8% in Africa and South Asia by 2050.[3]

Increases in the frequency or intensity of some extreme weather events will also increase disruptions in food distribution by damaging existing infrastructures or slowing food shipments. These disruptions, in turn, will lead to increased risk for food damage, spoilage, or contamination.[1,34] Any damage to the food supply, or disruption in food distribution, is likely to raise prices.[34-37]

Direct CO_2 fertilization is expected to effect plant photosynthesis. Higher concentrations of CO_2 stimulate growth and carbohydrate production in some plants, but can lower the levels of protein and essential minerals in a number of crops, including wheat, rice, and potatoes, with potentially negative implications for human nutrition.[1,8,35]

The incidence of food-borne illnesses will depend on the efficacy of practices that safeguard food (e.g., through adaptation plans) and monitor supply and access.[10,30,35-37] Crops and farming practices may also be modified to be more resilient to environmental stresses (e.g., drought tolerance). There are already international collaborations to incorporate climate change in national nutrition plans.[38]

Mental Health

Climate change may affect mental health *directly* by exposing people to trauma.[1,39,40] It may *indirectly* affect mental health by affecting (1) individual health and well-being (e.g., extreme heat exposure could affect laborers and thus affect livelihood) and (2) community well-being (e.g., violence, migration, civil unrest).[39,40] For example, "…climate change can indirectly increase risks of violent conflicts in the form of civil war and inter-group violence by amplifying well-documented drivers of these conflicts such as poverty and economic shocks."[1] One example of such amplification is the estimate that climate change and food insecurity could amplify civil unrest and conflict in 32 developing countries, including Bangladesh, Nigeria, India, Philippines, and Myanmar.[41]

The mental health consequences of climate change range from (1) minimal stress and distress symptoms; (2) clinical disorders, such as anxiety, depression, and posttraumatic stress; (3) substance abuse; (4) interpersonal violence exposure or perpetration; and (5) suicidality.[1,39,40] Some people may be at higher risk for mental health consequences, including children, the elderly, people with pre-existing mental illness, economically disadvantaged individuals, and first responders.[1,39,40] Other high-risk individuals are those who live in communities that rely on the natural environment for their livelihood (e.g., farming communities) and those in low-income areas who have limited opportunities to escape extreme weather (or those who are forced to migrate from their homes to escape).[1,39,40]

Among the preventive measures are effective disaster responses, both immediately and for an extended period after a climate-related disaster, effective risk assessment and identification of vulnerable groups, and preparedness to reduce risk. Public health professionals can increase community resilience by (1) developing adaptive capacities for economic development after a disaster, (2) reducing risk and resource inequalities, (3) decreasing social isolation, (4) improving public education about how individuals can protect themselves, and (5) engaging community stakeholders in disaster preparedness and response to ensure community-responsive (and thus effective) plans.[30,39,40]

Conclusion

Climate change is already causing—and is expected to continue to cause—a range of health conditions that vary by geography, community, and individual risk factors.[1,3-10,12-29,31-33,36,39,40] The vulnerability of any group is a function of its sensitivity to climate change-related health risks, its exposure to those risks, and its capacity to respond or cope.[1,9,11,12,30] The most vulnerable people include those of low-income, uninsured individuals, indigenous people, children, older adults, certain occupational groups, persons with disabilities, and persons with pre-existing or chronic medical conditions.[1,5] The effects of climate change could thus exacerbate social inequalities and health inequities. Climate change may disproportionately burden the most defenseless of our citizens. For example, the WHO estimates that the majority of the disease burden attributable to climate change falls on children who are younger than 5 years-old.[15]

International assemblies of scientists, health professionals, and climate experts affiliated with the WHO,[15] the Lancet,[6,9,10] UNICEF,[29] the US Global Change Research Program,[1] the Intergovernmental Panel on Climate Change (IPCC),[30] the Rockefeller Foundation,[7] and other agencies/organizations, call for urgent action to combat climate change and its impacts. Climate change has been called the "greatest health opportunity of the 21st Century,"[10] an ethical crisis,[42] and a problem for which public health professionals are ethically bound to address because of its current, and potential, disproportionate effects on our must vulnerable citizens.[11]

References

1. US Global Change Research Program. National climate assessment. [Internet]. 2014. Available from: http://nca2014.globalchange.gov.
2. International Energy Agency. Energy and climate change: world energy outlook special report. [Internet]. 2015. Available from: http://z.umn.edu/intnlea.
3. Patz JA, Frumkin H, Holloway T, et al. Climate change: challenges and opportunities for global health. JAMA 2014;312(15):1565-80. Available from: http://jamanetwork.com/journals/jama/fullarticle/1909928.
4. Campbell-Lendrum DH, Corvalán CF, Prüss Ustün A. How much disease could climate change cause? In: McMichael AJ, Campbell-Lendrum DH, Corvalan CF, et al. (Eds). Climate change and human health: risks and responses. Geneva: WHO. 2003. Available from: http://www.who.int/globalchange/summary/en/index6.html3.
5. Smith KR, Woodward A, Campbell-Lendrum D, et al. Human health: impacts, adaptation, and co-benefits. In: Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change [Field CB, Barros VR, Dokken DJ, et al. (Eds.)]. Cambridge and New York: Cambridge University Press. 2014. Available from: https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap11_FINAL.pdf.
6. Costello A, Abbas M, Allen A, et al. Managing the health effects of climate change. Lancet 2009;373(9676):1693-733. Available from: http://z.umn.edu/costello.
7. Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet 2015;386(10007):1973-2028. Available from: https://www.rockefellerfoundation.org/report/safeguarding-human-health-anthropocene-epoch.
8. Haines A, Kovats RS, Campbell-Lendrum D, et al. Climate change and human health: impacts, vulnerability and public health. Public Health 2006;120(7):585-96. Available from: https://pdfs.semanticscholar.org/c237/332fd97e96f792189277475575798b93b429.pdf.
9. Watts N, Adger N, Agnolucci P, et al. Health and climate change: policy responses to protect public health. Lancet 2015;386:1861-914.
10. Watts N, Adger WN, Ayeb-Karlsson S, et al. The Lancet Countdown: tracking progress on health and climate change. Lancet. 2016;389:1151-64. Available from: https://collections.unu.edu/eserv/UNU:5861/Lancet_Countdown_Final_paper.pdf.
11. Frumkin H, Hess J, Luber G, et al. Climate change: the public health response. Am J Public Health;2008:98(3):435-45. Available from: http://z.umn.edu/frumkin.
12. Brown H, Spickett J, Katscherian D. A health impact assessment framework for assessing vulnerability and adaptation planning for climate change. Int J Environ Research Public Health 2014;11(12):12896-914. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4276652/.
13. Levy B, Patz J. Climate change and public health. New York: Oxford University Press. 2015.
14. Huber DG, Gulledge J. Extreme weather and climate change: understanding the link and managing the risks. Center for Climate and Energy Solutions. [Internet]. 2011. Available from: https://www.c2es.org/publications/extreme-weather-and-climate-change.
15. Neira M. Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. World Health Organization. 2016. Available from: http://www.who.int/quantifying_ehimpacts/publications/preventing-disease/en/.
16. Basu R. Disorders related to heat waves. In: Climate change and public health. Levy B, Patz J (Eds). New York: Oxford University Press. 2015. pp 87-103.
17. Ngo NS, Horton RM. Climate change and fetal health: the impacts of exposure to extreme temperatures in New York City. Environ Res 2016;144:158-64.
18. Robine JM, Cheung SL, Le Roy S, et al. Death toll exceeded 70,000 in Europe during the summer of 2003. C R Biol 2008;331(2):171-8. Available from: http://www.precaution.org/lib/heat_kills_70000_in_europe_2003.080601.pdf.
19. Matsueda M. Predictability of Euro-Russian blocking in summer of 2010. Geophys Res Lett 2011;38(6). Available from: http://onlinelibrary.wiley.com/doi/10.1029/2010GL046557/full.
20. Barriopedro D, Fischer EM, Luterbacher J, et al. The hot summer of 2010: redrawing the temperature record map of Europe. Science 2011;332(6026):220-4.
21. US Environmental Protection Agency. Heat island effect. [Internet]. 2016. Available from: https://www.epa.gov/heat-islands.
22. Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity—an increasing challenge for low- and middle-income countries during climate change. Glob Health Action 2009;2:1-6.
23. Ahern M, Kovats RS, Wilkinson P, et al. Global health impacts of floods: epidemiologic evidence. Epidemiol Rev 2005;27(1):36-46.
24. CNN Library. Hurricane Katrina fast facts. [Internet]. 2016. Available from: http://www.cnn.com/2013/08/23/us/hurricane-katrina-statistics-fast-facts/.
25. Reisen WK. Vector-borne diseases. In: Climate change and public health. Levy B, Patz J (Eds). New York: Oxford University Press. 2015. pp 129-55.
26. Kinney PK, Ito K, Weinberger KR, et al. Respiratory and allergic disorders. In: Climate change and public health. Levy B, Patz J (Eds). New York: Oxford University Press. 2015. pp 105-27.
27. Brauer M, Amann M, Burnett RT, et al. Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. Environ Sci Technol 2012;46(2):652-60. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4043337/.
28. Johnston FH, Henderson SB, Chen Y, et al. Estimated global mortality attributable to smoke from landscape fires. Environ Health Perspect 2012;120(5):695-701. Available from: http://z.umn.edu/johnston.
29. UNICEF. Clean the air for children. [Internet]. 2016. Available from: https://www.unicef.org/publications/index_92957.html.
30. Intergovernmental Panel on Climate Change. Working Group III. Climate change fifth assessment report. Mitigation of climate change. [Internet]. 2014. Available from: https://www.ipcc.ch/report/ar5/wg3/.
31. Rose JB, Wu F. Waterborne and foodborne diseases. In: Climate change and public health. Levy B, Patz J (Eds). New York: Oxford University Press. 2015. pp 157-72.
32. Cann KF, Thomas DR, Salmon RL, et al.. Extreme water-related weather events and waterborne disease. Epidemiol Infect 2013;141(4):671-86. Available from: http://z.umn.edu/cann.
33. Uejio CK, Yale SH, Malecki K, et al. Drinking water systems, hydrology, and childhood gastrointestinal illness in Central and Northern Wisconsin. Am J Public Health 2014;104(4):639-46. Available from: http://z.umn.edu/uejio.
34. Food and Agricultural Organization of the United Nations. The state of food insecurity in the world. [Internet]. 2014. Available from: http://www.fao.org/3/a-i4030e.pdf.
35. US Global Change Research Program. Climate change, global food security, and the US food system. [Internet]. 2015. Available from: https://www.usda.gov/oce/climate_change/FoodSecurity2015Assessment/FullAssessment.pdf.
36. Chakraborty S, Newton AC. Climate change, plant diseases and food security: an overview. Plant Pathol 2011;60(1):2-14. Available from: http://onlinelibrary.wiley.com/doi/10.1111/j.1365-3059.2010.02411.x/full.
37. The CGIAR Research Program on Climate Change, Agriculture and Food Security. Available from: https://ccafs.cgiar.org/about-us#.WOASx461tSx.
38. Scaling Up Nutrition. Checklist on the criteria and characteristics of "good" national nutrition plans. [Internet]. Available from: http://z.umn.edu/scaleup.
39. Berry HL, Bowen K, Kjellstrom T. Climate change and mental health: a causal pathways framework. Int J Public Health 2010;55(2):123-32. Available from: http://z.umn.edu/barry.
40. Doherty TJ. Mental health impacts. In: Climate change and public health. Levy B, Patz J (Eds). New York: Oxford University Press. 2015. pp 195-214.
41. Verisk Maplecroft. Environmental risk dataset 2017. [Internet]. 2017. Available from: http://z.umn.edu/maplecroft.
42. Patz JA, Gibbs HK, Foley JA, et al. Climate change and global health: quantifying a growing ethical crisis. EcoHealth 2007; 4(4):397-405. Available from: http://www.gibbs-lab.com/wp-content/uploads/2015/09/Gibbs_Climate_change_and_global_health_2007.pdf.

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Climate Change and Vector-borne Diseases in Minnesota

by Franny Dorr, MPH


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Vector-borne diseases are of increasing concern in Minnesota. The total number of confirmed Lyme disease cases reported to the Minnesota Department of Health (MDH) from 2006-2015 increased greater than 200% compared to the number of cases reported from 1996-2005. In the same time period the blacklegged tick (formerly known as the deer tick), which transmits most tick-borne diseases in Minnesota, has expanded its geographical range substantially within the state. West Nile virus disease, the most frequently reported mosquito-borne disease in Minnesota (transmitted to humans by *Culex tarsalis*), has fluctuated annually in terms of case numbers but has remained an important public health issue since it was first reported in the state in 2002.

The story of vector-borne diseases in Minnesota is not unlike that in many other parts of the country: it features marked increases in case numbers of some diseases, the appearance of new diseases, and marked geographic expansion of some vectors over time. While there are many factors that contribute to the expansion and increase of vectors and disease cases, the single factor that has caught the most attention from the scientific community and the public alike is climate change. This article will briefly discuss the relationships between climate, climate change, and vector-borne diseases. It will also discuss other contributing factors that make predicting human risk of vector-borne disease so challenging.

Vector-borne Diseases in Minnesota

Vector-borne diseases are caused by disease agents (most commonly bacteria, viruses, or protozoa) that are transmitted to humans by arthropod vectors, most commonly ticks or mosquitoes.[1,2] Most endemic vector-borne disease agents in Minnesota cycle back and forth between arthropod vectors and animal reservoir hosts, usually mammals or birds, which maintain the disease agents in nature.[1,2] Humans acquire vector-borne diseases incidentally when arthropod vectors bite them instead of biting animal hosts.[1,2]

Climate, which affects both short and long-term weather conditions, plays a key role in the life cycle, activity, and geographic distribution of both vectors and animal hosts, which in turn affects the dynamics of pathogen transmission.[1-4] Vector life cycles and activity are particularly affected by climatic conditions because vectors are acutely sensitive to weather indicators such as temperature, relative humidity, precipitation, and wind.[2,3,5]

In Minnesota, the strong seasonal component to vector activity is apparent in the annual patterns of vector-borne disease cases reported to MDH. From 1996-2015, nearly 70% of all confirmed Lyme disease cases reported to MDH had illness onset during the months of June, July, or August.[6] From 2002-2015, 97% of all West Nile virus disease cases reported to MDH had illness onset during the months of July, August, or September.[7] However, particular attention is being paid to how climate change may influence vectors, reservoir species, pathogen transmission dynamics, and subsequent human risk of vector-borne diseases over the long term.

Climate Change and Vector-borne Diseases

Due to the biological sensitivities of vector and host species to climate conditions, it is logical to conclude that climate change will likely have significant direct and indirect impacts on vector-borne diseases in Minnesota.[2] Reservoir host populations may have greater fluctuations following extreme weather events or altered migration periods with warmer winters and longer warm seasons,[2,4] which could lead to a change in risk for West Nile virus in Minnesota. Additionally, warmer winters and longer warm seasons may lengthen seasonal activity or speed up development of both ticks and mosquitoes.[2,3]

Biological or behavioral changes in vectors and reservoir hosts in response to climate change will likely alter transmission dynamics as well. For example, warmer sustained temperatures may speed up virus development within mosquito vectors or alter distribution throughout the state for either tick- or mosquito-borne disease agents.[2-4] A shift in geographic distribution of existing vectors or animal reservoirs is also possible, depending upon the ability of these species to adapt and survive under new conditions.[2-4]

In addition to climatic variables, there are socioeconomic, demographic, cultural, and behavioral factors that heavily influence vector-borne disease risk.

Beyond Climate Change: A Complex Epidemiology

Given what is known about the relationship between climate and vector-borne diseases, especially how changes in climate may affect transmission dynamics, there are still other important considerations to keep in mind before drawing any conclusions about the impacts of climate change on human risk for vector-borne diseases.

Many other factors make understanding vector-borne disease risk extremely complex, even in the absence of climate change. In addition to climatic variables, there are socioeconomic, demographic, cultural, and behavioral factors that heavily influence vector-borne disease risk.[2-5] For example, land-use changes such as re-forestation or residential/commercial development in wooded areas have led to increased human interaction with the blacklegged tick habitat and have been a key driver of the increase of Lyme disease and other tick-borne diseases in the US.[4]

Cultural and behavioral factors also drive vector-borne disease risk in Minnesota. People who work or recreate in areas with known vector-borne disease risks may not take precautions to avoid bites, therefore increasing their risk of infection. Until we have a more reliable way to measure the interplay of all these factors, the true effect of climate change on vector-borne disease risk will remain cloudy at best.

A recent paper by researchers from the University of Minnesota and the MDH highlighted the complexity of measuring the factors affecting changes in the epidemiology of vector-borne diseases in Minnesota. The authors described a 742% increase in tick-borne disease incidence from 1996 through 2011 and a concurrent marked geographic expansion of the blacklegged tick. Using these data, they constructed a multivariate landscape epidemiological model to discern the impacts of spatial, climatic, vegetative cover, and host-related risk factors influencing this spread. This model was then used to project future risk of Lyme disease in Minnesota through the year 2100. Analyses showed that the two most important factors influencing the spread of Lyme disease in Minnesota, historically and into the future, are available forested habitat and temperature (defined as degree-days above 0 degrees Fahrenheit).[8] While this article is useful in communicating the potential future risk of Lyme disease in Minnesota, it did not address or evaluate the role of human behavior, leaving lingering questions. Understanding how all non-climatic variables contribute independently and interactively to vector-borne disease risk remains one of the major challenges to quantifying the true effects of climate change on vector-borne diseases.[5]

Ongoing Work to Monitor the Effects of Climate Change and Other Factors on Vector-borne Diseases

Despite the complexities involved in understanding and evaluating vector-borne disease risk, there is great work happening on a national level to quantify the effects of climate change on human health. In 2016, the US Global Change Research Program released a climate and health assessment, titled *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*.[9] This nine-chapter assessment provides excellent in-depth discussion and key findings, written by field experts, on many aspects of health-related impacts of climate change, including vector-borne diseases. This document is one of many that is laying the groundwork to strengthen our ability to quantify the health-related impacts of climate change.

In Minnesota, MDH is concerned about how changes in climate could alter vector-borne disease risks in the state and strives to address climate change in its work. Vector-borne disease epidemiologists at MDH are committed to continue long-term monitoring of vector-borne disease incidence, vector distribution, and pathogen prevalence, as well as increasing their understanding about how climate and other factors influence these parameters.

For More Information

For information about the epidemiology and prevention of vector-borne diseases in Minnesota for the public, health professionals, and international travelers, go to http://www.health.state.mn.us/divs/idepc/dtopics/vectorborne.

References

1. Minnesota Department of Health. Vector-borne diseases and climate change. [Internet]. 2014. Available from: http://www.health.state.mn.us/divs/idepc/dtopics/vectorborne/climate.html.
2. Beard CB, Eisen RJ, Barker CM, et al. Ch. 5: Vectorborne diseases. *The impacts of climate change on human health in the United States: a scientific assessment*. US Global Change Research Program, Washington, DC, 129–56. 2016. [Internet]. Available from: http://dx.doi.org/10.7930/J0765C7V.
3. Gage KL, Burkot TR, Eisen RJ, et al. Climate and vectorborne diseases. Am J Prev Med 2008;35(5):436-50.
4. Gubler DJ, Reiter P, Ebi KL, et al. Climate variability and change in the United States: potential impacts on vector- and rodent-borne diseases. Environ Health Perspect 2001; 109(Suppl 2):223–33.
5. Parham PE, Waldock J, Christophides GK, et al. Climate, environmental and socio-economic change: weighing up the balance in vector-borne disease transmission. Philos Trans R Soc B Biol Sci. 2015;370(1665).
6. Minnesota Department of Health. Tick-transmitted disease statistics. [Internet]. 2014. Available from: http://www.health.state.mn.us/divs/idepc/dtopics/tickborne/statistics.html.
7. Minnesota Department of Health. (2002-2015). Mosquito-transmitted disease statistics [Data file].
8. Robinson SJ, Neitzel DF, Moen RA, et al. Disease risk in a dynamic environment: the spread of tick-borne pathogens in Minnesota, USA. EcoHealth 2015; 12(1):152-63. Available from: http://doi.org/10.1007/s10393-014-0979-y.
9. Balbus AJ, Gamble JL, Beard JE, et al. The impacts of climate change on human health in the United States: a scientific assessment. US Global Change Research Program, Washington DC. [Internet]. 2016. Available from: https://health2016.globalchange.gov.

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"Without water vapor, the Earth's surface would be held fast in the iron grip of frost."
— John Tyndall

Global Climate and Public Health:
Imagining the Global Future

by William A. Toscano, PhD and Hitakshi Sehgal, MPH

William A. Toscano

Hitakshi Sehgal

Our understanding of climate change science is not new. The current warming of the Earth's temperature is irrefutably related to human activity. The many—and severe—environmental and health consequences of climate change require immediate action.

The "Greenhouse Effect" is Well Established

The evidence about the effects of heat absorption by gases in our atmosphere is not new. In the early 19th Century, John Tyndall was the first person to prove the "Greenhouse Effect."[1] His work built on Joseph Fourier's experiments showing that atmospheric gases absorb infrared irradiation (i.e., heat). Without the heat absorption capacity of atmospheric gases by solar irradiation the Earth would be a dead rock. Life as we know it could not exist.

In the late 19th Century, Svante Arrhenius, the Swedish Noble-prize winning scientist, was the first person to make a quantitative link between the heat-absorbing capability of carbon dioxide (CO_2) and warming of the ground. He further observed that the amount of CO_2 in the atmosphere was increasing because of the use of coal, which powered the Industrial Revolution. He proposed not only that the CO_2 in the atmosphere would increase but there would also be a concomitant warming of the planet.[2]

The atmospheric gases capable of absorbing infrared irradiation are referred to as *greenhouse gases*.[3] The most abundant greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons. They accumulate in the troposphere, the lowest region of the Earth's atmosphere. The troposphere starts at the earth's surface and goes up about 4-6 miles above sea level. In the natural order of things, solar energy passes through the atmosphere and warms the surface of the planet. Most of the solar irradiation escapes back into space and the earth cools (Figure 1).

Carbon Dioxide (CO_2) Increases Lead to Higher Temperatures

The surface temperature of the Earth is determined by the balance between incoming solar radiation and outgoing infrared radiation. *Radiative forcing* is a measure of the capacity of a gas to affect that balance (i.e., it reflects the difference between the absorption of solar energy retained by Earth and the amount radiated back to space).[4,5] Positive radiative forcing increases the earth's energy budget: with an increase in heat absorption (greenhouse gases), the temperature of the Earth proportionately increases. Thus, as CO_2 in the atmosphere increases, the temperature of the planet increases.[5]

As can be seen on Table 1, the concentrations of the most notorious positive radiative forcing gases have increased since the Industrial Revolution, with the most rapid increase occurring between 1970 and now.[6] In the1950s, as observations that the temperature of the Earth was gradually continuing to warm, environmental health scientists were concerned that if the warming trend did not abate, life as we know it would be threatened.[7-9]

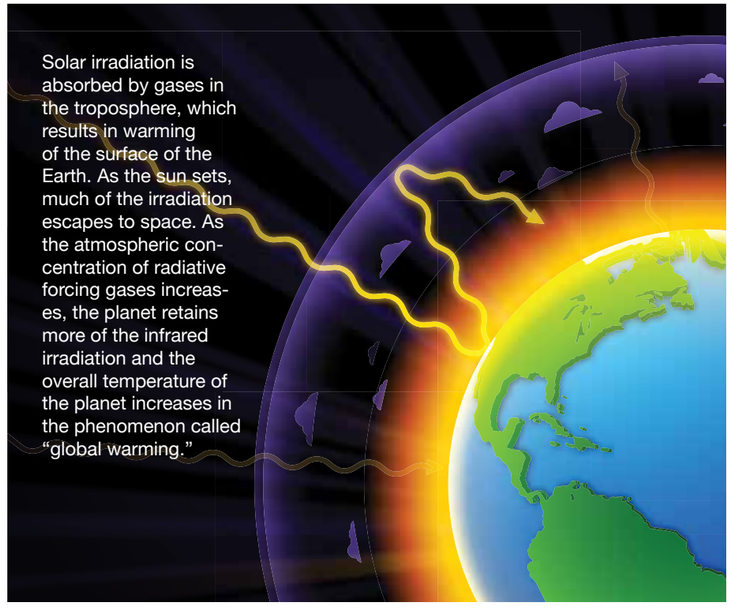
An important evidence-based document about climate change is the 2013 Fifth Assessment Report on the Physical Science Basis for Climate Change. It was written by the multi-national, multidisciplinary Intergovernmental Panel on Climate Change (IPCC).[6] The IPCC stated that, "*Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen."*[6]

Human Activity is the Most Important Influence on Climate Change

The IPCC authors stated that, *"Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850…In the Northern Hemisphere, 1983-2012 was likely the warmest 30-year period of the last 1400 years."*[6] The greatest concern is that the climate is changing at an alarming rate, which is unprecedented in 22,000 years.[10]

An important message from the IPCC scientists is that it is "extremely likely" that human influence is the dominant cause of greenhouse gas increases and thus of climate change.[6] That climate change is occurring because of human activity has been denied by some conservative think tanks.[11,12] However, survey data of prevailing attitudes of American citizens show that a majority believe that the climate is changing with a corresponding threat to public health; those who think that climate change is a hoax are from more conservative parts of the US.[13-15]

Figure 1: Planet Heating Cycle



Consequences of Climate Change

Climate change will, and already has, affected our environments and, directly and indirectly, health conditions. Models predict that the most dramatic environmental and health effects will be in low-income countries,[16] shifting the burden of global climate change to the world's poorest populations. For example:

- Global total rainfall has not changed, but geographic and temporal patterns, as well as the intensity, of ice melts, river flooding, droughts, and monsoons have changed.[17-20]
- Models predict that global yields from agriculture will decrease, which could lead to food shortages and changes in dietary composition, which would disproportionately affect poorer nations.[21-25]
- Global climate change negatively affects (and is affected by) air pollution and smog, which establishes environments that can lead to increased lung disease, allergies, and asthma.[26-30] For example, an increase in inhalable particles and ground level ozone increases air pollution[31,32] and is associated with increases in lung diseases in young children and adults.[33]
- Climate-induced increases in heat waves have increase heat-related conditions (e.g., heat strokes).[16,34]
- Global climate change may affect non-communicable or chronic diseases.[32]
- Climate change will increase the incidence of infectious diseases.[35] Specifically, vector-borne diseases, such as malaria, dengue fever, and chikungunya, may increase their area of coverage because global climate change extends the habitats in which vectors live.[36-38] For malaria, infection rates are higher in children aged 2–10 years, but most infected people are in other age groups, and the actual numbers have decreased somewhat in Africa because of concerted efforts by world aid organizations.[39] A surge in chikungunya has occurred in India and in the Americas.[40] The rapid rise in dengue fever cases in the Americas (Table 2) is attributed to global climate change brought about by anthropogenic activities.[36,41]

Table 1: Characteristics of Select Greenhouse Gases Relevant to Radiative Forcing.

Greenhouse Gas	Pre-1750 (Industrial Revolution) Atmospheric Concentration	2014 Atmospheric Concentration	Human Source	GWP 100 years[a]	Atmospheric Lifetime (years)
Carbon Dioxide	~280 ppm	399.5 ppm	Fossil fuel use, land use changes	1	100-300
Methane	722 ppb	1834 ppb	Fossil fuel, agriculture, waste dumps, microbes	28	12.4
Nitrous Oxide	270 ppb	328 ppb	Agriculture, Industrial processes, fossil fuel use	265	121
Ozone	237 ppb	337 ppb	Ozone is not directly emitted into the atmosphere. It forms when oxides of nitrogen and volatile organic compounds are in the air and sunlight is present.	NA	Hours to days
Chlorofluorocarbons	0 ppt	72 ppt	Coolants	5,820	85
Perfluorocarbons	0 ppt	80 ppt	Coolants, electronics, aluminum industry	Varies (~5,000-9,000)	Varies (~2,600-50,000)
Sulfur hexafluoride	0 ppt	8.6	Insulators, electronics magnesium industry	23,500	3200

Source of data: Table 8.A.1. Myhre GD, Shindell F-M, Bréon W, et al. Anthropogenic and natural radiative forcing. In: Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker TF, Qin D, Plattner G-K, et al. (eds.)]. Cambridge University Press: Cambridge, United Kingdom and New York. [Internet]. 2014. Available from: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.

Abbreviations: ppm=parts per million; ppb=parts per billion; ppt=parts per trillion; GWP=Global Warming Potential. [a] GWP (Global Warming Potential) provides a measure of the radiative effects of emissions of various greenhouse gases, integrated over a specified time (in this table, 100 years) relative to an equal mass of CO_2 emissions. The GWP with respect to CO_2 is = 1 The short lifetime of ozone (hours-days) precludes a meaningful calculation of GWP.

Table 2: Number of Dengue Fever Cases in the Americas, 2000–2015.

Year	Number of Cases
2000	400,519
2005	427,627
2010	1,663,276
2016	2,338,848

Source: Pan American Health Organization. Number of reported dengue cases, region of the Americas. [Internet]. 2016. Available from: http://z.umn.edu/pahodengue.

Conclusion

The climate is changing because of anthropogenic activity. As the climate changes, shifting weather patterns are observed, including late monsoons, drought and desertification.[12,17,20] These changes have serious consequences on agriculture and the ability to provide proper nutrition to a growing global population.[22-25] With improper nutrition, an increase in susceptibility to infectious and non-communicable diseases is observed.[32,42] Increases in heat waves and heat-related deaths,[16,33] as well as an increase in vector-borne diseases, have occurred.[32,36,40]

Climate model projections, driven by anticipated future greenhouse gas and aerosol emissions, indicate that the Earth will continue to warm, with associated increases in sea level and extreme weather events.[6] These projections paint a grim picture of the future,[6,43] but the projections need not come true. It is possible to take measures to mitigate current global climate change predictions by modifying behaviors and instituting policies and programs that promote less reliance on fossil fuels, sustainable agricultural practices, and technological advances to mitigate and prevent pollution.[6,20,24,44]

Carbon Dioxide is the Most Damaging Greenhouse Gas

There is a small but vocal minority who refute the science of climate change. Their arguments are based on misinformation, falsehoods, or partial information that downplay the fact that burning fossil fuels—such as gasoline, coal, oil, and natural gas—results in the production of carbon dioxide. More specifically, they may deny the importance of carbon dioxide as a major contributor to climate change.

One common distortion by those who are opposed to reducing atmospheric carbon dioxide involves the factual assertion that the Global Warming Potential of some gases, such as methane, is higher than that of carbon dioxide. The Global Warming Potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere. Carbon dioxide is used as the reference for this measure, so the Global Warming Potential for any other gas is relative to carbon dioxide. The measure for methane, for example, is between 25-28 (i.e., methane traps 25-28 times more heat in the atmosphere than carbon dioxide).

Focusing on just one measure—the Global Warming Potential—and the absence of discussion about other factors that contribute to the damage done by greenhouse gases distorts the science. The Global Warming Potential (how strongly a greenhouse gas absorbs energy) is important, but so are two other characteristics of greenhouse gases: how long they stay in the atmosphere and how much (how concentrated) the gases are in the atmosphere. Thus while methane has a higher Global Warming Potential than carbon dioxide, it has a much shorter atmospheric lifetime than carbon dioxide. Methane lasts about a decade in the atmosphere and concentrates fairly slowly. In contrast, the carbon dioxide that we produce by burning fossil fuels far exceeds the rate of natural processes that remove it from the atmosphere. Its concentration increases much more than any of the other heat-absorbing gases (including methane).

The lifetime of carbon dioxide and its high concentration is why it is the most damaging greenhouse gas. Methane has about one-third of the effect of carbon dioxide on climate change.

For more information about greenhouse gases, go to the US Environmental Protection Agency's site at https://www.epa.gov/ghgemissions.

For More Information

For more information about the science of climate change, there are many resources (see the list of Resources in this volume on page 68 for just a few of them). One of the most comprehensive is the Intergovernmental Panel on Climate Change's 2013 report, available from: https://www.ipcc.ch/report/ar5/wg1.

References

1. Hulme M. On the origin of the Tyndall Effect: John Tyndall's 1859 *Interrogation of Nature*. Weather 2009;64:121-3.
2. Crawford ET. Arrhenius: from ionic theory to the greenhouse effect. Canton OH: Science History Publications (Uppsala Studies in History of Science, Volume 23), 320 pp. 1996.
3. Mathez EA. Climate change: the science of global warming and our energy future. New York: Columbia University Press. 2009.
4. Hansen J, Sato M, Ruedy R. Radiative forcing and climate response. Atmosphere 1997;102:6831-64.
5. Marotzke J, Forster PM. Forcing, feedback and internal variability in global temperature trends. Nature 2015;517:565-70.
6. Intergovernmental Panel on Climate Change. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker TF, Qin D, Plattner G-K, et al., (eds.)]. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA. 2014. [Internet]. Available from: https://www.ipcc.ch/report/ar5/wg1.
7. Cox PM, Betts RA, Jones CD, et al. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature 2000;408:184-7.
8. Patz JA, Levy BS. Applying public health to climate change. IN: Climate change and public health (Patz JA, Levy BS, Eds). New York: Oxford University Press, pp 55-119. 2015.
9. Weart S. The discovery of global warming, 2nd ed. Cambridge, MA: Harvard University Press. 2008.
10. Joos F, Spahn R. Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years. Proc Natl Acad Sci 2007;105:1425-30.
11. Jacques PJ, Dunlap RE, Freeman M. The organisation of denial: conservative think tanks and environmental scepticism. Environ Politics 2008;17:349-85.
12. Moran A. Climate change: the facts. Woodsville, New Hampshire: Stockade. 2015.
13. Akerlof K, DeBono R, Berry P, et al. Public perceptions of climate change as a human health risk: surveys of the United States, Canada and Malta. Int J Environ Res Public Health 2010;7:2559-606.
14. Jang M, Hart PS. Polarized frames on climate change and global warming across countries and states: evidence from Twitter big data. Glob Environ Change 2015;32:11-7.
15. Mailbach FW, Kreslake JM, Roser-Renouf C, et al. Do Americans understand that global warming is harmful to human health? Evidence from a national survey. Ann Glob Health 2015;81:396-409.
16. Harrington LJ, Frame DJ, Fischer EM, et al. Poorest countries experience earlier anthropogenic emergence of daily temperature extremes. Environ Res Lett 2016;11:055007.
17. Dai A. Drought under global warming. Wire's Clim Change 2011;2:245-65.
18. Kumar KK, Rajagopalan K, Cane MA. On the weakening relationship between the Indian monsoon and ENSO. Science 1999;284:2156-9.
19. McMichael P. Development and social change: a global perspective, 6th Ed. SAGE. 2017.
20. King A, Donat MG, Fischer EM, et al. The timing of anthropogenic emergence in simulated climate extremes. Environ Res Lett 2015;10:094015.
21. Bowen KJ, Friel S. Climate change adaptation: where does global health fit in the agenda? Globalization and Health 2012;8(1):10.
22. Jones PG, Thornton PK. Potential impacts of climate change on maize production in Africa and Latin America in 2055. Global Climate Change 2003;13:51-9.
23. Mendelsohn R, Nordhaus WD, Shaw D. 1994. The impact of global warming on agriculture: a Ricardian analysis. Amer Econ Rev 1994;84:753-71.
24. Olesen JE, Bindi M. Consequences of climate change for European agricultural productivity, land use and policy. Eur J Agron 2014;16:239-62.
25. Parry ML, Rosenzweig C, Iglesias A, et al. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Climate Change 2004;14:53-67.
26. Fenger J. Air pollution in the last 50 years–from local to global. Atmos Environ 2009; 43:13-22.
27. Jacob DJ, Winner DA. Effect of climate change on air quality. Atmos Environ 2009; 43:51-63.
28. Kinny PL. Climate change, air quality, and human health. Am J Prev Med 2008;35:459-67.
29. Monks PS, Granier C, Fuzzi S, et al. Atmospheric composition change–global and regional air quality. Atmos Environ 2009;43:5268-350.
30. Ramanathan V, Feng Y. Air pollution, greenhouse gases and climate change: global and regional perspectives. Atmos Dev 2009;43:37-50.
31. Guamieri M, Balmes R. Outdoor air pollution and asthma. Lancet 2014;383:1581-92.
32. Kjellstrom T, Butler AJ, Lucas RM, et al. Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. Int J Public Health 2010;55:97-103.

Human-made Climate Change Reached New Heights in 2016

The United Nations World Meteorological Organisation (WMO) warned that 2016 would stand out because of the "alarming" and "unprecedented" rates of greenhouse gas emissions, making it the hottest year on record. According to the WMO, *"The globally averaged temperature in 2016 was about 1.1°C higher than the pre-industrial period. It was approximately 0.83° Celsius above the long term average (14°C) of the WMO 1961-1990 reference period, and about 0.07°C warmer than the previous record set in 2015."*

Why is this significant? For the last 10,000 years, the Earth's temperature has been fairly steady, fluctuating by only about one degree Celsius. It is thought that an average increase in temperature above 2°C higher than the pre-Industrial Revolution period could have profound effects on environmental quality. Scientists suggest, for example, that we will likely see longer droughts and more intense heat waves, which could cause big disruptions to the world's food supply. A two-degree increase could cause sea levels to rise several feet, which would flood many coastal communities in the US. Such an increase would also potentially cause large migrations of people from countries like Bangladesh, India, and Vietnam. Because this seemingly small increase could have large effects—and because it is not clear how human and other species will adapt to them—the aim of the historical international Paris Agreement is to *"…strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius."* WMO's report that the average temperature in 2016 was 1.1°C higher than the pre-Industrial Revolution period is thus highly concerning.

For More Information

- An infographic depiction of severe weather events in 2016 is at https://www.ncdc.noaa.gov/sotc/service/global/extremes/201613.gif.
- WMO's press release is at http://z.umn.edu/unwmo.
- Information about the Paris Agreement is at http://unfccc.int/paris_agreement/items/9485.php.

33. Cao LM, Zhou Y, Sun WW, et al. Impacts of airborne particulate matter and its components on respiratory system health. Chinese J Prevent Med 2016;12:1114-8.
34. Robins J-M, Cheung SLK, LeRoy S, et al. Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies 2008;331:171-8.
35. Altizer S, Ostfeld RS, Johnson PTJ, et al. Climate change and infectious diseases: from evidence to a predictive framework. Science 2013;341:514-9.
36. Hales S, deWet N, Maindonald J, et al. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. Lancet 2002;360:830-4.
37. Emmert V, Fink AH, Morse AP, et al. The impact of regional climate change on malaria risk due to greenhouse forcing and land-use changes in Tropical Africa. Environ Health Perspect 2012;120:77-84.
38. Rogers D, Randolph SE. The global spread of malaria in a future, warmer world. Science 2000;289:1763-6.
39. World Health Organization. World Malaria Report. Geneva: WHO. 2016.
40. Diop D, Mesezenikov G, Sanicas M. Chikungunya outbreaks from 2000 to 2015: a review. MO J Publ Health 2015;2(6):00043.
41. Sheffield PE, Landrigan PJ. Global climate change and children's health: threats and strategies for prevention. Environ Health Perspect 2011;119:291-8.
42. Gluckman PD, Hanson M, Mitchell MD. Developmental origins of health and disease: reducing the burden of chronic disease in the next generation. Genomic Med 2010; 2:14.
43. Hjerpe M, Linner B-O. Utopian and dystopian thought in climate change science and policy. Futures 2009;41:234-45.
44. Gould S, Rudolph L. Challenges and opportunities for advancing work on climate change and public health. Int J Environ Res Public Health 2015;12:15649-15672.

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Bill Toscano: Teaching Globalization and Health (PubH 7262) at the University of Minnesota

Global health concerns cross the borders of developed and developing nations. This class will focus on the effect of globalization on social and scientific consequences in public health. Topics will include the interplay between global stressors such as population, war, economics, urbanization and environment and their effects on the health of women and children, the spread of infectious and chronic diseases, nutrition and environmental health.

US National Climate Assessment

A team of more than 300 experts guided by a 60-member Federal Advisory Committee produced a report of the May 2014 Third National Climate Assessment for the US. The materials were reviewed by the public, experts, and a panel of the National Academy of Sciences. The report has 12 major sections that collectively provide a primer on climate change in the US. Among the topics covered are:

- How the climate has changed (and is expected to change) in the US;
- Extreme weather events;
- Effects of climate change on human health effects and infrastructure;
- Concerns about the water supply, agriculture, oceans, biodiversity, and indigenous peoples; and
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The report also has special sections about climate change for each region in the US. A key message of this federal report is that, "Substantial adaptation planning is occurring in the public and private sectors and at all levels of government; however, few measures have been implemented and those that have appear to be incremental changes."

The report is available at http://nca2014.globalchange.gov.

The Promise of Big Data in Understanding Climate Change

by Anuj Karpatne, MTech and Vipin Kumar, ME, PhD

Anuj Karpatne, Department of Computer Science and Engineering

Vipin Kumar, Department of Computer Science and Engineering

The start of the 21st Century can be rightfully termed as the *Big Data Era*. Our ability to collect, store, and access large volumes of information is accelerating at unprecedented rates, thanks to better sensor technologies, more powerful computing platforms, and greater online connectivity. The deluge of data[1,2] has pervaded every walk of our life, from satellite sensors in space to wearable computing devices and from credit card transactions to electronic healthcare records. As we further advance in the *Big Data Era*, the volume, variety, and veracity of information that is being collected and made available is only projected to grow in the foreseeable future.

With advances in big data collection and storage technologies, there has been a simultaneous revolution in our ability to process and analyze large volumes of data, collectively referred to as the emerging field of *data science*. This includes a broad range of computational and statistical methods for extracting useful knowledge from the data, spanning multiple research areas such as database technologies, data mining, machine learning, and artificial intelligence. Some of the common tasks in data science research include the extraction of frequent patterns (e.g., groups of genetic markers that co-express together), learning of relationships among variables (e.g., the effect of a medical intervention on the health outcome of a subject), and summarization of information (e.g., grouping of brain regions based on their neuronal activity).

The start of the 21st Century can be rightfully termed as the Big Data Era.

Data science methods have hugely impacted the state-of-the-art in a number of applications including online ad placements and product recommendations, natural language translation, image processing, and most recently, autonomous driving.[3] Having transformed commercial industries such as retail, advertising, and transportation, the rapidly growing field of data science also holds great promise for accelerating our understanding of climate change and its impacts.

Opportunities for Big Data in Climate Science

Climate science has experienced a rapid transformation from a data-poor to a data-rich phase in the last few decades, with data from Earth-observing satellites launched by organizations such as the National Aeronautics and Space Administration (NASA), SpaceX, and the European Space Agency (ESA), as well as massive volumes of data from model simulations that are being generated by multiple groups of climate scientists across the world.

The growing size and richness of climate data provide numerous opportunities for data science to improve our understanding of the Earth's climate. They also provide answers to some of the pressing questions related to climate change mitigation and adaptation.[4,5]

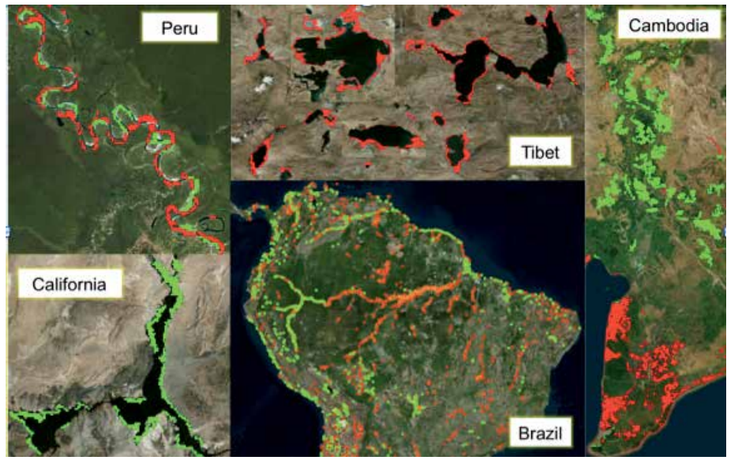

Figure 1. Examples of changes identified by our global surface water monitoring system (green indicates loss of water and red indicates gain in water in the last 15 years). This includes river migrations in floodplains of Peru (possibly aided by increased soil erosion due to deforestation in the Amazonian tropical forests), expanding glacial lakes in Tibet due to melting glaciers, declining water supplies in drought-stricken lakes of California and Cambodia, and increasing constructions of dams and reservoirs in Brazil and around the world that have a variety of ecological impacts. **Sources:** Authors and Bing Maps.

First, data science methods can play a major role in discovering key climatic processes such as teleconnections, which represent pairs of distant regions in the world that show coupled climate activity. A well-known example of such phenomena is the El Nino Southern Oscillation in the West Pacific Ocean. Automated discovery of teleconnections using data science methods (e.g., recent network-based algorithms)[6] can help us discover previously unknown phenomena in climate.[7,8] Insights gained from such analyses can also help in evaluating and refining climate models based on their ability to reproduce vital climatic processes.

Second, the vast amount of remote sensing data being collected by Earth-observing satellites can help us monitor critical environmental resources and their interactions with the changing climate. Some examples include monitoring the dynamics of surface water bodies[9,10] that are impacted by changing climate and human actions (Figure 1), mapping tropical forest fires[11] that are one of the major contributors of greenhouse gas emissions worldwide, and understanding how extreme rainfall patterns are impacted by climate change.[12]

Challenges and Research Needs

Although big data in climate offers numerous research opportunities and the data science community is increasingly becoming eager to explore applications in climate domains,[13] there are a number of challenges in utilizing the full potential in climate data for accelerating scientific discovery, relative to the level of success achieved by data science in the commercial arena.

One challenge is that, while traditional data science algorithms are designed for handling well-defined objects, such as items bought in market-basket transactions or lists of friends in social networks, objects of interest in climate science often appear as loosely defined patterns in continuous space-time fields that evolve over space and time. For example, ocean eddies (swirling bodies of water and nutrients in the ocean) appear as changes in sea surface height data with loose boundaries around their edges.

Another challenge is that climate science problems often involve the complex nature of relationships among physical variables that are difficult to extract from the limited number of climate records. For example, high-quality sensor measurements of climate variables on a global scale are only available for the recent past (i.e., the last 40-100 years). This limits the usefulness of several state-of-the-art data science algorithms such as deep learning; its success in speech and image recognition problems has been greatly enabled by the internet-scale availability of data in these domains. In fact, black-box data science methods, that are oblivious to the rich understanding of the physical processes driving climatic phenomena, have met with limited success in climate science.[14]

To fully capitalize the power of big data for accelerating scientific discovery in the domain of climate, there is an increasing interest in developing a systematic way of integrating climate science knowledge in state-of-the-art data science algorithms. This *theory-guided data science* paradigm[15,16] is expected to be a key enabler in advancing our knowledge of the Earth's climate system and informing adaptation and mitigation policies related to combating climate change.

For More Information

A recent article by one of the authors (Kumar) describes the opportunities and challenges of using big data in climate change research and calls for theory-guided approaches in the use of big data.[15] It is available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4174912.

References

1. Bell G, Hey T, Szalay A, Beyond the data deluge. Science 2009; 323 (5919):1297–8.
2. Manyika J, Chui M, Brown B, et al. Big data: the next frontier for innovation, competition, and productivity. [Internet]. The McKinsey Global Institute, 2011. Available from: http://abesit.in/wp-content/uploads/2014/07/big-data-frontier.pdf.
3. Halevy A, Norvig P, Pereira F. The unreasonable effectiveness of data. IEEE Intell Syst 2009;24(2):8-12.
4. University of Minnesota. Expeditions in computing. Understanding climate change: a data driven approach. [Internet]. 2012. Available from: http://climatechange.cs.umn.edu.
5. National Science Foundation. Discovery: using data to better understand climate change. [Internet]. 2016. Available from: https://nsf.gov/discoveries/disc_summ.jsp?cntn_id=189519.
6. Kawale J, Liess S, Kumar A, et al. A graph-based approach to find teleconnections in climate data. Stat Anal Data Min 2013;6(3):158-79.
7. Lu M, Lall U, Kawale J, et al. Exploring the predictability of 30-day extreme precipitation occurrence using a global SST–SLP correlation network. J Clim 2016;29(3):1013-29.
8. Liess S, Kumar A, Snyder PK, et al. Different modes of variability over the Tasman Sea: implications for regional climate. J Clim 2014;27(22):8466-86.
9. Khandelwal A, Karpatne M, Marlier J, et al. An approach for global monitoring of surface water extent variations using MODIS data. [Internet]. 2016. Available from: https://pdfs.semanticscholar.org/ea1b/9484a178fc45ec6ea52d03fa43f6c916ccfb.pdf.
10. University of Minnesota. Global surface water monitoring system. [Internet]. Available from: http://z.umn.edu/monitoringwater.
11. University of Minnesota. Fire viewer. [Internet]. Available from: http://arizona-umh.cs.umn.edu/FireMonitorRelease-landsat/.
12. Ghosh S, Das D, Kao SC, et al. Lack of uniform trends but increasing spatial variability in observed Indian rainfall extremes. Nat Clim Chang 2012; 2(2):86-91.
13. Climate Informatics. [Internet]. Available from: http://climateinformatics.org/?q=node/1.
14. Caldwell PM, Bretherton CS, Zelinka MD, et al. Statistical significance of climate sensitivity predictors obtained by data mining. Geophys Res Lett 2014;41(5):1803–8.
15. Faghmous JH, Kumar V. A big data guide to understanding climate change: the case for theory-guided data science. Big Data 2014;2(3):155-63.
16. Karpatne A, Atluri G, Faghmous J, et al. Theory-guided data science: a new paradigm for scientific discovery. IEEE Trans Knowl Data Eng 2016. arXiv: 1612.08544.arXiv preprint arXiv:1612.08544. 2016 Dec 27. Available from: https://arxiv.org/pdf/1612.08544.pdf.

Pushing the Boundaries of Computer Science Research in Climate Change

University of Minnesota researchers, led by Dr. Vipin Kumar, have embarked on a multi-institution project to push the boundaries of computer science research for understanding climate change. This 5-year $10 million project, funded by the National Science Foundation's Expeditions in Computing Program, is addressing some of the key challenges in climate change research by developing methods that use *"…climate and ecosystem data available from satellite and ground-based sensors, the observational record for atmospheric, oceanic, and terrestrial processes, and physics-based climate model simulations. These innovative approaches help provide an improved understanding of the complex nature of the Earth system and the mechanisms contributing to the adverse consequences of climate change, such as increased frequency and intensity of hurricanes, precipitation regime shifts, and the propensity for extreme weather events that result in environmental disasters."*

The project's website, http://climatechange.cs.umn.edu/index.php, provides methodological articles, access to data software and tools, replication of key presentations made by its investigators, and many other resources for individuals interested in methods to better understand climate change.

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Vipin Kumar is a Regents Professor at the University of Minnesota, where he holds the William Norris Endowed Chair in the Department of Computer Science and Engineering.

National Listserve for MCH Students & Graduates

A listserve for past and present Maternal and Child Health (MCH) graduate students (from all disciplines) is available from the Maternal Child Health Bureau (MCHB) through the Association of University Centers on Disabilities (AUCD). The listserve helps MCH graduates and students continue to maintain the strong connections they have made during their degree programs and connect with MCH-ers from other disciplines and programs. This listserve facilitates great opportunities to collaborate on research, network, and share best practices and questions with peers. To subscribe and learn more about this listserve, visit z.umn.edu/aucd.

Climate Change Awareness, Capacity and Preparation in Illinois Health Departments

by Elena Grossman, MPH

Source: Author

Elena Grossman

The US 2014 Third National Climate Assessment for the Midwest projected that climate change would affect various sectors including agriculture, transportation, infrastructure, ecosystems, as well as public health.[1] The key findings related to public health included increased heat waves and intensity, degraded air quality, reduced water quality, and increased rainfall events and flooding.[1] A myriad of adverse health outcomes are correlated with these changes including heat-related illnesses, respiratory illnesses, water- and vector-borne illnesses, and mental health conditions.[1,2]

The Environmental Defense Fund, George Mason University, and the National Association of County and City Health Officials (NACCHO) conducted a survey in 2008 and in 2012 of local health department directors from around the country to better understand their perceptions of climate-related health risks and the capacity of their health departments to adequately develop programs, plans, and policies to address them.[3,4] In both surveys, the majority of respondents believed that their jurisdiction had already experienced climate change, would experience serious public health problems because of it, and that they themselves were knowledgeable about the potential health impacts of climate change.[3,4] On the other hand, the majority also stated that they lacked expertise in assessing the local health impacts of climate change, developing solutions to address it, and obtaining adequate resources to protect their communities against climate change.[3,4]

To better understand the climate change resources needed by Illinois public health professionals, the Building Resilience Against Climate Effects–Illinois Project (BRACE-Illinois) is working with the Illinois Department of Public Health (IDPH) to build the capacity of Illinois' public health system to better prepare for the health effects of climate change. In order to improve the readiness of Illinois' local health departments, BRACE-Illinois conducted the *Illinois Climate and Health Survey* in 2013 and 2016. The objective of the surveys was to better understand the extent to which Illinois' local health departments were thinking about climate change, their perceived level of preparation for climate change, and their knowledge and perceived capacity to develop strategies for dealing with climate change.

The Survey of Illinois Local Health Departments

Three previously disseminated surveys were used to create a tool for assessing Illinois' local health departments.[3,5,6] Questions from these surveys were selected, tailored for Illinois' public health system and climate, and compiled to produce the online *Illinois Climate and Health Survey*. BRACE-Illinois' Training and Education Work Group reviewed and edited the tool. The survey link was disseminated to the Public Health Administrators of all 96 local county health departments in Illinois through the Illinois Association of Public Health Administrators, the Northern Illinois Public Health Consortium, and the Southern Illinois Public Health Consortium. The Public Health Administrator was asked to complete the survey and to consult with colleagues who were familiar with the issues addressed in the survey. The survey was available to complete for three weeks and reminder emails were sent out to encourage response. (See survey questions on page 47).

Health Departments Were Aware, But There Were Knowledge, Preparation, and Resource Gaps

Thirty-four percent of the local health departments responded in 2013 and 27% in 2016. In 2013, 76% of the respondents were administrators, executive directors, or directors of the health department; 75% held these positions in 2016.

Climate change was not identified as a high priority in either survey. In both surveys, two-thirds of the respondents reported that they themselves were knowledgeable about the potential local public health impacts of climate change in their county (64% in 2013, 67% in 2016). They were not as confident that they had the knowledge and expertise needed to develop strategies for dealing with it (47% in 2013, 52% in 2016). Even fewer said that they believed their health department had the capacity to address climate change (39% in 2013, 41% in 2016). They were even less confident that their health care delivery system had the knowledge and expertise (45% in 2013, 33% in 2016) or the capacity (31% in 2013, 22% in 2016).

An overwhelming majority of the respondents stated that their public health departments had **not** undertaken any programs, procedures, or policies specifically designed to respond to the effects of climate change (88% in 2013, 82% in 2016). Yet respondents in both surveys identified some climate-related plans, policies, or programs currently in place. Furthermore, they acknowledged that their departments used climate-related information in program planning or implementation to address a variety of climate-sensitive public health concerns.

Table 1 shows the respondents' perceptions about existing or planned climate-related plans, policies, or programs at their local health departments. Some programs (e.g., systems to track vector-borne diseases, emergency preparedness) were more likely to be developed than others (e.g., public education on health and climate, ozone alert notification systems) in both survey years.

Table 2 shows the respondents' perceptions about using climate-related information to inform the planning or implementation of activities. Similarly, some programs (e.g., vector-borne diseases, water- and food-borne diseases, storms and floods) were more likely to use climate information than others (e.g., air quality, mental health conditions).

[The survey results provided a] foundation to send three clear messages to local health departments: they are already doing some relevant work, implementing activities to address climate change does not necessarily mean allocating additional resources, and climate change information can be incorporated into existing program.

Questions. The survey questions were binary, ordinal, closed-ended, and open-ended. The questions required respondents to reflect on themselves, their public health departments, and the public health system in their community. *Climate change* was defined as *"any significant variation in temperature, precipitation, wind, or other type of weather that lasts for decades or longer…not based on any single event or even weather in a single year."* Key questions were:

- *Climate change as a priority*. Respondents were given a list of 20 health-related items (e.g., diet, cancer, obesity, diabetes) and one open-ended option. Climate change and extreme weather events were two of the 20 options. Respondents were asked to select the top five public health priorities from this list for their health department.
- *Knowledge about the potential health effects of climate change.* Respondents were asked if they strongly disagree, disagree, agree, strongly agree, or don't know about their personal knowledge about the potential health effects of climate change.
- *Perception about capacity to address climate change.* Respondents were asked if they strongly disagree, disagree, agree, strongly agree, or don't know with three individuals questions about (1) their health department having the capacity (defined as resources, knowledge, and authority) to develop climate change strategies; (2) the knowledge and expertise of their county's health care delivery system to develop climate change strategies; and (3) the capacity of their county's health care delivery system to develop climate change strategies.
- *Response to climate change.* Respondents were asked (yes/no) if their department had undertaken programs or changed procedures or policies to respond to climate change.
- *Existence of programs that would address climate change.* Respondents were given a list of 11 programs and asked to indicate if their departments had such a program in place, had plans to develop one, or had no plans to pursue.
- *Use of information to plan climate-change related activities.* Respondents were given a list of 12 climate-change related issues and asked if their department used any information on climatic patterns, disease, or syndromic surveillance data to plan activities to address them.

Table 1: Climate-related Programs that Local Health Departments in Illinois Had in Place, Were Planning to Develop, or Had No Plans to Pursue, BRACE-Illinois Surveys, 2013 and 2016.

Program	2013 Illinois Survey (n=36)			2016 Illinois Survey (n=30)		
	In Place	Planning	No Plans	In Place	Planning	No Plans
Public health and climate change education program	3%	23%	74%	15%	26%	59%
System to track vector-borne diseases	84%	9%	6%	89%	0%	11%
Emergency preparedness plans for climate related events	65%	16%	19%	59%	26%	15%
Ozone alert notification system	3%	0%	97%	11%	7%	81%
Heat warning Systems	29%	16%	55%	44%	7%	48%
Identification of at risk populations	56%	31%	13%	44%	26%	30%
Ground water monitoring for droughts	17%	10%	72%	15%	15%	70%

Opportunities to Improve Climate Change Preparedness in Illinois

Our survey had low response rates in both years, which calls into question the representativeness of our findings. The low response rates also mean that the differences in percent responses over the two time periods do not necessarily reflect changes in status (i.e., in programs and/or data use). Finally, we assume that the respondents were knowledgeable about their program's priorities and resources. Because the majority of the respondents were administrators, we feel that is a tenable assumption, although we did not specifically assess knowledge. Overall, the survey respondents provided us with some insight about the knowledge and perceived capacity of the local health departments at which they were employed.

The survey results revealed clear needs for (1) educational tools for community leadership and members, (2) capacity building for local health department leadership and staff, and (3) opportunities to incorporate climate-related information into existing activities. Importantly, our respondents were not confident about the knowledge and capacity of their county's health care delivery system to prepare for, and respond to, climate change.

While local health departments may not have designed systems with climate change in mind, many appeared to have—or were planning—related activities, such as syndromic surveillance, vector-borne disease surveillance, water- and food-borne outbreak investigation, and emergency preparedness for storms and floods. The existence of relevant activities provides a foundation to send three clear messages to local health departments: they are already doing some relevant work, implementing activities to address climate change does not necessarily mean allocating additional resources, and climate change information can be incorporated into existing programs.

Climate-related activities vary in how technical they are, with some not requiring substantial resources. For example, less than half of the respondents reported that their health departments had plans to develop educational programs about climate and health. The development of educational programs is a less technical undertaking compared to other efforts (e.g., ozone alert notification systems) and involves processes (e.g., creating, adapting, or adopting materials) that are familiar to public health professionals. Local health departments can take a relatively easy step to recognize the importance of climate change by updating existing educational materials with climate change information.

BRACE-Illinois, IDPH, and other BRACE programs and state health departments can be important resources for local health departments who want to engage in activities related to climate change and health. For example, BRACE-Illinois and IDPH have developed toolkits and trainings, as well as provided mini-grants for local health departments to build their capacity to address the public health implications of climate change. Such information is available at:

- BRACE-Illinois, https://braceillinois.uic.edu
- The Centers for Disease Control and Prevention's BRACE: https://www.cdc.gov/climateandhealth/brace.htm
- The National Climate Assessment, http://nca2014.globalchange.gov
- The Climate and Health Assessment, https://health2016.globalchange.gov

Table 2: Issues about Which Illinois Health Departments Used Climatic Patterns, Diseases, or Syndromic Surveillance Data in Planning or Program Implementation, BRACE-Illinois Surveys, 2013 and 2016.

Content Area for Which Climate-Related Information Was Used for Planning or Program Implementation	2013 Illinois Survey (n=36)	2016 Illinois Survey (n=30)
	Local Health Departments that Reported Use of Data for Content Area (%)	Local Health Departments that Reported Use of Data for Content Area (%)
Vector-borne infectious diseases	72%	96%
Water- and food-borne diseases	58%	64%
Food safety and security	53%	64%
Storms and floods	50%	56%
Unsafe or ineffective sewage and septic system operation	44%	52%
Heat waves and heat-related illnesses	33%	40%
Droughts	22%	28%
Health care services for people with chronic conditions during service disruptions	22%	24%
Quality or quantity of fresh water	17%	20%
Housing for residents displaced by extreme weather events	11%	16%
Anxiety/ depression or other mental health conditions	8%	12%
Quality of the air	6%	8%

References

1. Melillo JM, Richmond T, Yohe GW. (Eds.) Climate change impacts in the United States: the Third National Climate Assessment. [Internet]. Washington DC: U.S. Global Change Research Program. 2014. Available from: http://www.globalchange.gov/browse/reports/climate-change-impacts-united-states-third-national-climate-assessment-0.
2. Patz JA, Frumkin H, Holloway T, et al. Climate change: challenges and opportunities for global health. JAMA 2014;312(15):1565-80. Available from: http://jamanetwork.com/journals/jama/fullarticle/1909928.
3. Balbus J, Ebi K, Finzer L, et al. Are we ready? Preparing for the public health challenges of climate change. [Internet]. Washington, D.C.: National Association of County and City Health Officials, Environmental Defense Fund, and George Mason University. 2008. Available from: http://www.naccho.org/uploads/downloadable-resources/Are-we-ready_14_view.pdf.
4. National Association of County and City Health Officials. Are we ready? Preparing for the public health challenges of climate change. Report 2. [Internet]. 2014. Available from: http://z.umn.edu/naccho.
5. The Climate Leadership Initiative and the Oregon Coalition of Local Health Officials. Climate change health preparedness in Oregon: an assessment of awareness, preparation and resource needs for potential public health risks associated with climate change. [Internet]. 2009. Available from: http://z.umn.edu/oregon.
6. Public Policy Institute of California. Climate change and California's local public health agencies. [Internet]. 2008. Available from: http://www.ppic.org/content/pubs/op/OP_208LBOP.pdf.

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Video: Climate Change, Public Health, and Preparing for More Extreme Weather

View a 10-minute video on climate change, public health, and emergency preparedness that describes:

- How climate and weather are complementary—but different—concepts;
- Recent changes in weather patterns in the Midwest and how they increase risks for extreme weather events;
- How extreme weather events can affect health, especially the health of vulnerable individuals; and
- How data can help public health professionals protect citizens from extreme weather events.

The video was developed through a collaboration of the Building Resilience Against Climate Effects (BRACE)-Illinois Project at the University of Illinois at Chicago School of Public Health and the Illinois Department of Public Health. The video is especially relevant for public health professionals and others who are involved in emergency preparedness. It is available at https://www.youtube.com/watch?v=ST3Xs0H_NmU.

US National Climate Assessment

A team of more than 300 experts guided by a 60-member Federal Advisory Committee produced a report of the May 2014 Third National Climate Assessment for the US. The materials were reviewed by the public, experts, and a panel of the National Academy of Sciences. The report has 12 major sections that collectively provide a primer on climate change in the US. Among the topics covered are:

- How the climate has changed (and is expected to change) in the US;
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The report also has special sections about climate change for each region in the US. A key message of this federal report is that,*"Substantial adaptation planning is occurring in the public and private sectors and at all levels of government; however, few measures have been implemented and those that have appear to be incremental changes."*

The report is available at http://nca2014.globalchange.gov.

Video: How Climate Change is Affecting Health of the People in Illinois

This 7-minute video provides a discussion about individual vulnerability to extreme weather events. A metereologist recalls the hundreds of heat-related deaths in Chicago in the 1990s. Professionals discuss who is the most vulnerable to extreme weather and how they can be protected. And three Illinois residents share their stories about how floods, heat, and poor air quality permanently changed their health and altered their well-being. This video brings a personal perspective to the global phenomenon of climate-related health effects and is appropriate for public health professionals, healthcare providers, community based organizations, educators, and the general public. It was developed through a collaboration of the Building Resilience Against Climate Effects (BRACE)-Illinois Project at the University of Illinois at Chicago School of Public Health and the Illinois Department of Public Health. It is available at https://www.youtube.com/watch?v=AdRNm7vvIFc

Wind power. **Source:** https://pixabay.com/en/windräder-wind-park-lake-energy-408596/.

Environmental Resilience in the Age of the Anthropcene

by Wendy L. Hellerstedt, MPH, PhD & Kristin K. Raab, MLA, MPH

We may be entering a new geological age. Human impact has been so profound on the Earth's geology and ecosystems that the International Geological Congress is considering officially recognizing a new age—the Anthropocene or the Age of Man. The Holocene, the epoch we are currently in, represents 12,000 years of stable climate during which human civilization developed and thrived. This age may be coming to an end.

Since the 1950s there has been unprecedented acceleration of carbon dioxide emissions and the manipulation of land by deforestation and human development, marking the beginning of an age dominated by humans. Industrialization and other human activities have increased carbon dioxide levels from 280 parts per million to 400 parts per million in the last 150 years.[1] These atmospheric changes have led to changes in our climate that threaten our health and, perhaps, our survival.

The American Meteorological Society stated that, "*There is unequivocal evidence that Earth's lower atmosphere, ocean, and land surface are warming; sea level is rising; and snow cover, mountain glaciers, and Arctic sea ice are shrinking… The observed warming will be irreversible for many years into the future, and even larger temperature increases will occur as greenhouse gases continue to accumulate in the atmosphere…The ongoing warming will increase risks and stresses to human societies, economies, ecosystems, and wildlife through the 21st century and beyond, making it imperative that society respond to a changing climate."*[2]

What was once a thriving planet, capable of absorbing human activities without significantly disrupting ecosystems and other species, has given way to an ailing planet unable to rebound from human's depletion of its myriad resources. As the risks

What is the Age of the Anthropocene?

Humans have come to have more impact on Earth and its health than any other species. The pace of human impact has been rapid in recent history, especially since the development of fossil fuels and urbanization (over half of the human population live in urban settings). A new geological era—the Anthropocene or the age of Man—has been proposed to replace the Holocene era of the last 12,000 years. In the Holocene, conditions were favorable for human development. Because of human activities, this is no longer the case and transformations are needed to sustain human development. The proposed new age is intended to not only reflect the effects of human activity, but to emphasize human accountability and responsibility to stimulate local and global actions to adapt and transform.

Definitions

Adaptability: The capacity to influence resilience.

Resilience: The capacity of a system to respond to shocks and disturbances, including unanticipated ones.

Social-ecological system: Integrated system of ecosystems and human society with reciprocal feedback and interdependence. This definition reflects the "humans-in-nature" perspective.

Transformability: The ability of a system to become a different kind of system when ecological, economic, or social structures make the existing system untenable.

Transformation: The deliberate initiation of a phased introduction of one or more variables at a lower scale, while maintaining the resilience of the system at higher scales as transformational change proceeds.

Source: Folke C, Carpenter SR, Walker B, et al. Resilience thinking: integrating resilience, adaptation, and transformability. Ecol Society 2010. Available from: http://www.ecologyandsociety.org/vol15/iss4/art20/.

from global climate change and unfettered growth intensify, so will the consequences for humanity and the natural environment. The acceleration and expansion of human activities have already resulted in pandemics; the mass extinction of species; disruptions in food, water, and energy supplies; extreme weather events; and human migration. Projections for the health and survival of the human species in the near future are grim unless change occurs.[3] The proposed new age—the Anthropocene—is intended to not only reflect the effects of human activity, but to emphasize human accountability and responsibility to stimulate local and global action to preserve the planet and our species.

Environmental Resilience

Environmental resilience, as defined by Carl Folke and others, offers hope and a framework for transforming the imminent catastrophic events driven by climate change through understanding and working with complicated and interdependent systems to better sustain human development and health. Among the key concepts of the environmental resilience framework are that:[4]

(1) humans and nature are strongly coupled and co-evolving and are one "social-ecological" system;

(2) change is inevitable and unpredictable and systems that govern our well-being are complex and dynamic; and

(3) resilience is not a return to the status quo, it is adapting and creating new alternative solutions that respond to our "intertwined human-environment planet."[4]

The social-ecological system. A key concept in environmental resilience is that humans both shape and depend on the biosphere. Humans and nature should be conceived of as one "social-ecological" system,[4] with "social" referring to the human aspects (individuals, cultures, and political and institutional domains) and "ecological" referring to the biosphere (the thin layer around Earth where there is life, including human life). Resilience will not occur when environmental issues are perceived as those outside of human responsibility. To address climate change, humans need to re-connect with the planet and acknowledge that they are a part of—not apart from—the biosphere.

Social-ecological systems are *"...intertwined systems of people and nature embedded in the biosphere..."*[4] and thus the health of one influences the health of the other. For example, burning fossil fuels pollutes the biosphere, escalating climate change and creating poor air quality, which affects human health. In other words, the health of the biosphere and "nature" are intrinsically linked to human health.

Change is complex. Environmental resilience acknowledges that change is inevitable and multifactorial. Folke and colleagues argue that a key behavioral response to the challenge of environmental resilience is to learn to live with change and uncertainty.[5] With climate change, past weather patterns can no longer be used to envisage the future. We must begin to "expect the unexpected" and plan accordingly.[6] Although difficult, accepting uncertainty will eventually help reduce anxiety and promote our ability to foster innovative and sustainable solutions.

Additionally, natural and human-made systems are in constant flux, unpredictable, and complex.[4] The systems that sustain life do not operate in a systematic way: they are messy, non-linear, and operate at various temporal and spatial scales, with different tipping points, feedback loops, and possible sudden shifts between states.[7] A resilient action will operate in complex environments and navigate unpredictable changes and disruptions. A resilient action will also sustain the flow of multiple ecosystems and the social and economic entities that depend on them. Thus, understanding, adapting, and transforming social-ecological systems demands interdisciplinary approaches, as well as awareness and inclusion of various cultural influencers. Resilience thinking is thus a dynamic concept about responding to a complex and unpredictable biosphere in a sustainable manner.

The proposed new age—the Anthropocene—is intended to not only reflect the effects of human activity, but to emphasize human accountability and responsibility to stimulate local and global action to preserve the planet and our species.

Adaptation and creativity. We must be prepared to turn environmental crises into opportunities. Resilience, as it relates to the environment and climate change, does not assume that returning to a former state is positive or even possible. Environmental resilience is about more than bouncing back from a bad situation. Resilience is about moving forward, in a sustainable and responsive way, not necessarily to repair or rebuild flawed structures or to return to stasis or the way things were in the past. It is about the ability of people, communities, and cultures to live in—and transform for the better—ever-changing environments to adapt to climate change and mitigate its negative consequences.

Strategies for Transformation and Adaptation

While there are no silver bullets for adapting to and thriving in the Anthropocene Age, Chapin et al.[8] offered the following six strategies (as summarized by Folke[4]) to deal with uncertainty and change and to transform unsustainable social-ecological pathways to potentially more favorable ones:

1. Maintain a diversity of options by:

- Prioritizing options that enable species to adjust to rapid environmental change;
- Sustaining a diversity of cultures, languages, and knowledge systems to provide multiple approaches; and
- Renewing the functional diversity of degraded systems.

2. Enhance social learning to facilitate adaptation by:

- Engaging multiple disciplinary perspectives;
- Developing transparent information systems to develop trust among stakeholders to build support for action;
- Using scenarios and simulations to explore consequences of proposed actions; and
- Exercising caution with plans that disrupt larger systems.

3. Adapt a governance to implement potential solutions by:

- Providing an environment that encourages leadership and respect; and
- Fostering social networking to build trust, bridge communications, and allow accountability among several organizations/stakeholders.

The Resistance Challenge

The following is Carl Folke's description of the resistance challenge:

"A lake, for example, can exist in either an oxygenated, clear state or an algae-dominated, murky one. A financial market can float on a housing bubble or settle into a basin of recession. Conventionally, we've tended to view the transition between such states as gradual. But there is increasing evidence that systems often don't respond to change in a smooth way: The clear lake seems hardly affected by fertilizer runoff until a critical threshold is passed, at which point the water abruptly goes turbid. Resilience science focuses on these sorts of regime shifts and tipping points. It looks at incremental stresses, such as accumulation of greenhouse gases in combination with chance events—things like storms, fires, even stock market crashes—that can tip a system into another equilibrium state from which it is difficult, if not impossible, to recover. How far can a system be perturbed before this shift happens? How much shock can a system absorb before it transforms into something fundamentally different? How can active transformations from an undesirable social-ecological state into a better one be orchestrated? That, in a nutshell, is the essence of the resilience challenge."

Source: Folke C. On resilience. SeedMagazine.com. [Internet]. 2010. Available from: http://seedmagazine.com/content/article/on_resilience/.

4. Prepare for transformation by:

- Engaging stakeholders to identify dysfunctional states and raise awareness of problems;
- Identifying thresholds, alternative actions, pathways, and triggers; and
- Identifying barriers to change, potential change agents, and strategies to achieve change.

5. Navigate the transformation by:

- Identifying potential crises and using them as opportunities for change;
- Maintaining flexible strategies and transparency; and
- Supporting institutions that facilitate cross-organizational communication and participation.

6. Build resilience of the new system by:

- Creating incentives and fostering values for stewardship of the new system;
- Initiating and maintaining social networks for problem solving; and
- Fostering interactions and support of decision-makers.

Michael Oakes: Teaching Social Epidemiology (PubH 6370) at the University of Minnesota

Social epidemiology is the branch of epidemiology that considers how social interactions and purposive human activity affect health. In other words, social epidemiology is about how a society's innumerable social interactions, past and present, yield differential exposures and thus differences in health outcomes between persons who make up populations. This discussion-based course addresses why toxic dumps often end up in one neighborhood instead of another, why some people have access to fresh produce, and why some enjoy resources such that they can purchase nice environments and excellent health care. I aim to introduce students to the foundational and cutting-edge issues, both theoretical and methodological, in the sub-discipline.

Resilience and Stewardship

Human welfare depends on the welfare of the environment and the biosphere. Species, including *Homo sapiens*, are interconnected across political and geographical boundaries—and the systems and communities that protect one part of the earth (water, air, land, species) affect all parts of the earth. Humans depend on multiple and diverse ecosystems for water, food, and other necessities. This interconnectedness and inter-reliance is the reason that all humans must be concerned with precipitation patterns, heat extremes, droughts, and Arctic melting, even if it is not occurring in their "backyard." Today, we are all in each other's backyard.[4] As we plan for a habitable planet, the environmental resilience framework encourages us to work together to anticipate, adapt, learn, and transform the social-ecological systems to keep all of us healthy.[4] And the framework demands multidisciplinary and multi-sectorial stakeholder engagement to create programs and policies that ensure the equitable distribution of benefits and power, fairness, and justice.

For More Information

This article was heavily informed by a comprehensive overview of resilience theory, as it applies to climate change, written by Carl Folke in September 2016. The article is available from http://z.umn.edu/folkeoxford. A March 2017 commentary by Martin Boucher in *Ensia* is one of many that reinforces that climate change mitigation will require social change, not just technical solutions. It is available from https://ensia.com/voices/climate-change-social-fix.

References

1. National Aeronautics and Space Administration. Global climate change. Vital signs of the planet. [Internet]. Available from: https://climate.nasa.gov/causes.
2. American Meteorological Society. Climate change. [Internet]. 2012. Available from: http://z.umn.edu/metereol.
3. World Health Organization. Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. Geneva: World Health Organization, 2016. Available from: http://z.umn.edu/whoenviron.
4. Folke C. Resilience. Oxford research encyclopedia of environmental science. Oxford University Press, New York, New York, USA, 2016. Available from: http://z.umn.edu/folkeoxford.
5. Folke C. Social-ecological resilience and behavioural responses. Beijer International Institute of Ecological Economics. 2002. Available from: http://www.beijer.kva.se/PDF/87823499_Disc155.pdf.
6. Kates RW, Clark WC. Environmental surprise: expecting the unexpected? Environment: Science and Policy for Sustainable Development 1996;38(2):6-34.
7. Folke C. On resilience. SeedMagazine.com. [Internet]. 2010. Available from: http://seedmagazine.com/content/article/on_resilience.
8. Chapin III FS, Kofinas GP, Folke C. (Eds.). Principles of ecosystem stewardship: resilience-based natural resource management in a changing world. New York: Springer. 2009.

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Heat-related health impacts are also a health equity issue.

Climate and Health in Wisconsin:

Assessing Vulnerabilities and Working with Priority Populations

by Colleen Moran, MPH, MS

Colleen Moran
Photo by Harriet Chen, courtesy of the Wisconsin Population Health Service Fellowship Program

As climate trends change across the globe, extreme weather events such as heavy precipitation, drought, and heat waves are becoming more common. In Wisconsin, average annual temperatures and precipitation have increased since 1950, and these trends are projected to continue through mid-century. Climate changes will create new risks that public health must be prepared to address. The anticipated health impacts are numerous: heat waves place vulnerable populations at risk for illness and premature death and extreme precipitation events can result in groundwater contamination and gastrointestinal illnesses. A warmer climate may also result in longer pollen seasons adversely affecting persons with asthma and allergies and transmission of vector-borne diseases such as Lyme disease and West Nile Virus may increase. The severity of these impacts will vary depending on location and the unique vulnerabilities of the populations affected. Public health will be most effective by employing adaptation strategies at a local level that are tailored to the specific needs of the population.

Addressing the Public Health Impacts of Climate and Extreme Weather

The Climate and Health Program (CHP) at the Wisconsin Department of Health Services has taken concrete steps to address health impacts at the local level. The Wisconsin CHP receives grant funding from the Centers for Disease Control and Prevention (CDC) to manage and implement a grant called Building Resilience Against Climate Effects (BRACE). BRACE employs a framework that involves five key steps:

1. ***Assessing*** vulnerabilities and forecasting climate-related health impacts;
2. ***Projecting*** disease burden;
3. ***Assessing*** climate-related public health interventions;
4. ***Developing and implementing*** a statewide climate and health adaptation plan; and
5. ***Evaluating*** activities to continually improve strategies to address the health impacts.

This grant has allowed the Wisconsin CHP to build needed capacity at the state and local levels to promote climate adaptation. This article presents an example of how this five-step process was used to address vulnerability to extreme heat events in Wisconsin.

Assessing Vulnerability: the Development of a Heat Vulnerability Index

Extreme heat is an important cause of morbidity and mortality and heat vulnerability has been identified as one of Wisconsin's greatest climate-related health concerns.[1] Heat-related health

Figure 1: Heat Vulnerability Index Variables

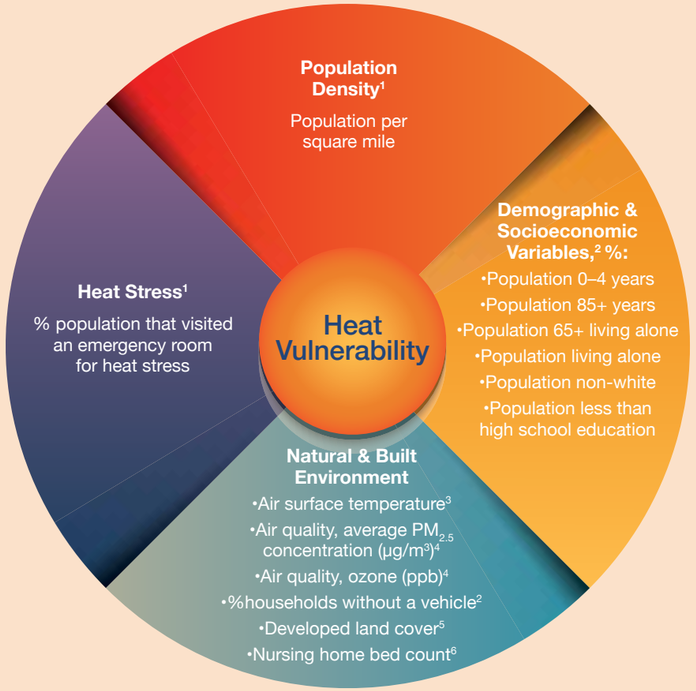


Figure 1. Heat Vulnerability Index Variables.

Data Sources: (1) US Census, 2011, block group; (2) US Census, American Community Survey (ACS) 2007-2011, block group; (3) Parameter-elevation Regressions on Independent Slopes Model (PRISM), 2012, Raster, 4-k resolution; (4) Environmental Protection Agency (EPA) Air Quality Index (AQI), 2012, Lat/long (extrapolated); (5) National Land Cover Database (NLCD), 2006, Raster, 30-m resolution; (6) Division of Long Term Care, 2013. Source: WI Dept of Health Services, https://www.dhs.wisconsin.gov/publications/p0/

impacts are also a health equity issue. Extreme heat may disproportionately affect populations that have greater exposure, increased sensitivity, and reduced adaptive capacity. For example, the elderly, the very young, pregnant women, socially isolated people, vulnerable occupational groups, and those with chronic medical conditions (e.g., cardiovascular disease) are more likely to experience adverse health effects.

In step one of the BRACE framework, assessing vulnerabilities and forecasting climate-related health impacts, the Wisconsin CHP created a Heat Vulnerability Index (HVI) for the entire state that included each of Wisconsin's 72 counties and 11 sovereign tribal nations.[2] An HVI is an analytical tool that measures vulnerability to adverse health effects from an extreme heat event. The Wisconsin CHP HVI used existing population and census data, and natural and built environment data, to assess vulnerability based on demographic, health, and environmental variables, consistent with methodologies used by other public health departments such as those used by the San Francisco Department of Public Health. Figure 1 lists the specific indicators that were used in the analysis.

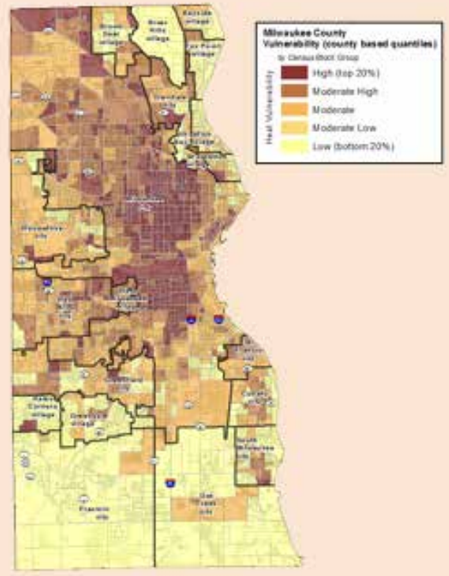
Wisconsin's HVI maps[3] can help identify high-risk census block groups and populations that may benefit from receiving targeted messaging related to heat events and additional resources during extreme heat events. These maps have been shared with local public health agencies, state, local, and tribal emergency management, and tribal health departments as a tool to help them plan for and address extreme heat events.

Implementing Adaptation and Intervention Strategies

Given that populations are not equally effected by extreme heat, the HVI allows the Wisconsin CHP to target its intervention and adaptation strategies by first addressing communities that are the most vulnerable to the effects of climate and therefore will be disproportionally impacted. The HVI analysis provides an efficient and effective tool in the selection of type and location of adaptation and intervention strategies. After completing the five-step BRACE framework that included identifying populations at greatest risk for extreme heat events and HVI map development, the Wisconsin CHP shifted focus towards implementing strategies that either interrupt the pathways between an exposure and a negative health outcome (i.e., an intervention strategy) or involve implementation plans to increase the resilience of a population to the negative health impacts of changing climate trends (i.e., an adaptation strategy).

The Wisconsin CHP is currently using the HVI to inform an epidemiological tool, Community Assessment for Public Health Emergency Response (CASPER).[4]

Figure 2: Milwaukee County Heat Vulnerability Index



Milwaukee County Heat Vulnerability Index.

Source: Wisconsin Department of Health Services, https://www.dhs.wisconsin.gov/publications/p01084-milwaukee.pdf.

CASPER is used by communities across the US to provide information at the household level about the capacity to respond to a disaster. CASPER is valuable because it can be done quickly and at a low cost.

The Wisconsin CHP will conduct Wisconsin's first CASPER in Milwaukee, Wisconsin because of its high vulnerability level as identified by the CHP's HVI (Figure 2). In the spring/summer of 2018 the CHP will gather detailed information on populations in Milwaukee that are vulnerable to extreme heat. The information will be used to enhance preparedness by identifying gaps in current plans and anticipating resource needs during an extreme heat event. This type of prospective heat-related CASPER has previously been conducted in Arizona.

Health Equity in Climate Adaptation

To build on the epidemiologic information provided by the HVI and CASPER, the Wisconsin CHP seeks to improve its understanding of the range and variability of health impacts throughout Wisconsin by seeking the input of priority populations that experience greater vulnerability to climate effects. By engaging priority populations and understanding how they will be most affected by an extreme heat event, the CHP can adequately address the most serious health impacts of a changing climate in Wisconsin. The creation of a Health Equity Action Team (HEAT) is thus the next necessary step in the program's strategic plan to ensure that Wisconsin residents most vulnerable to climate effects are represented in all planning and implementation processes.

The HEAT members will guide the development and refinement of the Wisconsin CHP's strategies by providing feedback on adaptation and intervention strategies and evaluation planning. For example, they will provide counsel about how to best implement CASPER. Their guidance is vital to building the Wisconsin CHP's capacity to reduce and prevent negative climate-related health outcomes and to build resilient communities across Wisconsin.

The HEAT members use multiple cultural perspectives and skills to provide an equity lens to the CHP's work. They do so by engaging with, and representing, many different priority populations, including low income, communities of color, immigrant groups (including those with limited English proficiency), indigenous peoples, children and pregnant women, older adults, vulnerable occupational groups, and persons with disabilities or chronic medical conditions. These populations experience disproportionate, multiple, and complex risks to their health and well-being, primarily because of the social determinants of health, which amplify, moderate, or influence climate-related health effects. The HEAT includes representatives from the Wisconsin Center for Health Equity (http://www.wche.org), the Great Lakes Inter-Tribal Epidemiology Center (http://www.glitc.org/programs/epi-home), and Family Health/La Clinica (http://www.famhealth.com). The HEAT convened its first in-person in mid-March 2017 and will continue to expand its membership as the program grows.

Moving Forward

The Wisconsin CHP recognizes its responsibility in preparing and protecting Wisconsinites from the health risks associated with a changing climate. Working through the CDC's five-step BRACE framework has allowed the Wisconsin CHP to build knowledge and capacity at both the state and local levels to better adapt to and remain resilient to these

changes. The ability of the Wisconsin CHP HVI analysis to inform CASPER and subsequent adaptation and intervention strategies is just one example of how the program is using evidence-based approaches to respond to Wisconsin's changing climate. And the involvement of the HEAT, with its equity lens, reflects Wisconsin CHP's acknowledgment that the most sustainable and effective work will be culturally relevant and responsive to Wisconsin's diverse communities. Moving forward, the Wisconsin CHP plans to continue increasing the knowledge and capacity of all of Wisconsin's citizens for adaptation and resilience to the health impacts of a changing climate.

For More Information

For more information about the Wisconsin Climate and Health Program in the Wisconsin Department of Health Services, go to https://www.dhs.wisconsin.gov/climate/index.htm. For more information on the BRACE Framework, visit the CDC site (https://www.cdc.gov/climateandhealth/brace.htm) and read an article by Marinucci, et al. (2014), *Building Resilience against Climate Effects—A Novel Framework to Facilitate Climate Readiness in Public Health Agencies,* at http://www.mdpi.com/1660-4601/11/6/6433/htm.

References

1. Wisconsin Department of Health Services. Wisconsin's changing climate. Impacts and adaptation. [Internet]. 2011. Available from: http://www.wicci.wisc.edu/report/2011_WICCI-Report.pdf.
2. Wisconsin Department of Health Services. Wisconsin Heat Vulnerability Index (HVI). [Internet]. 2014. Available from: https://www.dhs.wisconsin.gov/publications/p0/p00882.pdf.
3. Wisconsin Department of Health Services. Wisconsin Heat Vulnerability Index (HVI). [Internet]. Available from: https://www.dhs.wisconsin.gov/climate/wihvi.htm.
4. Centers for Disease Control and Prevention. Community Assessment for Public Health Emergency Response (CASPER). [Internet]. 2016. Available from: https://www.cdc.gov/nceh/hsb/disaster/casper.

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Rhonda Jones-Webb: Teaching Social Inequalities in Health (PubH 6055) at the University of Minnesota

We examine the causes of social inequalities in health and what can be done to reduce them in the US. We specifically examine individual, community, and policy level approaches to reducing health disparities. Students develop an understanding of: the use of constructs such as race, ethnicity, and social class in health research in the US; how data on race, ethnicity, and social class can be used to inform health interventions in the US; and the use of policy, community, institutional, and individual level strategies to reduce social inequalities in health. They apply concepts and tools learned to a specific health disparity issue. In addition to coursework, I also help direct an active and ongoing Health Equity Workgroup open to all students, staff, and faculty (z.umn.edu/hewg).

Reducing Health Disparities through Research, Teaching, and Community Outreach

The Center for Leadership Education in MCH faculty and staff are involved in the School of Public Health's (SPH) Health Equity Work Group. Members plan educational events (including an annual Health Disparities Roundtable) and provide leadership opportunities for students. Interested students can explore the SPH's Health Equity Minor (7-credits for MPH and 12-credits for PhD students) that allows them to specialize in studying health disparities and equity.

For more information visit sph.umn.edu/research/hewg.

Top 10 Reasons to Get a Master of Public Health (MPH) Degree in Maternal and Child Health (MCH)

1. MCH MPH graduates often work with—or on behalf of—socially and economically vulnerable populations that include women, children, youth, and family members.

2. MCH is one of the oldest—and one of the most varied—areas in national health promotion and assurance in the US and the world. MCH content areas are varied, including reproductive and prenatal health care access, newborn screening, family home visiting, care of children with special health care needs, and autism research. All of these initiatives require MCH professionals at national and local levels (z.umn. edu/mchb).

3. MCH MPH graduates develop public health programs and policies that focus on health promotion, health care equity, disease prevention, and primary care services. Their work is conducted in non profit organizations, government agencies, universities, school districts, advocacy organizations, health clinics, and research/academic institutions.

4. Every state—and many cities and counties—have departments specifically dedicated to MCH public health advocacy, assessment, and program development (e.g., see Minnesota's MCH section at z.umn.edu/mchmn).

5. MCH MPH-level epidemiologists participate in research teams to conduct needs assessments, evaluate programs, and identify and promote social and environmental conditions that contribute to the health of women, children, youth, and families. MCH professionals with epidemiologic skills are especially in demand in city, county, and state health departments.

6. MCH professionals are in heavy demand internationally. Most of the eight United Nations' Millennium Development Goals focus on MCH areas (z.umn. edu/unmdg), including eradicating poverty, reducing child mortality, empowering women/promoting gender equity, improving maternal health, and reducing the risk of HIV/AIDS and other diseases that affect vulnerable populations.

7. MCH professionals have organizations that help them network and that provide them with opportunities for continuing education: the Association of Teachers of Maternal and Child Health (www.atmch.org) and the Association of Maternal and Child Health Programs (www.amchp.org).

Get Your MPH in MCH at the University of Minnesota

8. Students can complete their MPH entirely online, in-person at our Twin Cities campus, or through a combination of online and in-person classes. For more information, visit the Program website at: www.sph.umn.edu/academics/degrees-programs/mph/mch.

9. The University of Minnesota's MCH Program has about 35 regular or adjunct faculty members, representing a variety of disciplines (e.g., pediatrics, nursing epidemiology, sociology, public health, psychology, anthropology) and community and academic work settings.

10. To prepare our students for leadership positions, they undertake field experiences with MCH leaders to enhance their research, program development, and policymaking skills.

Katherine Fennelly: Teaching Immigrant Health Issues (PA 5451) at the University of Minnesota

The demography of American communities is changing dramatically, but many of our institutions have not kept pace with the needs of new African, Asian, Eastern European, and Latino residents. Policymakers, educators, health care and social service providers who are used to working with European-origin families and some Latino residents are suddenly seeing refugees from countries such as Somalia, Ethiopia, Tibet, Cambodia, and the Sudan. The purpose of my course in immigrant health is to help students prepare to meet the needs of foreign-born residents by researching their characteristics and belief systems, as well as the context and motives for immigration, and to learn how to design public policies that will improve their health and well-being. [Note: I define "health" broadly to include issues of access to care and poverty, and public attitudes toward immigrants and refugees.] The key to becoming "culturally competent" is to go into the community to meet and learn from the residents you hope to serve. Community visits, observations, and interviews are an essential (and fun!) component of my teaching approach.

Framing Climate Change through the Lens of Health

by Nissa Tupper, MLA

Source: Author

Nissa Tupper

Climate change is one of the most compelling, complicated issues of our time and communicating effectively about it is no small feat. It is also one of the most pressing public health issues. It has been called the greatest global health challenge of the 21st Century because it threatens the very basics that we depend on for life.[1] Despite clear urgency related to our well-being, only one in four Americans can name at least one health problem related to climate change and 10% incorrectly cite that there are *no* health problems associated with it.[1,2]

Why is there a disconnect between the urgency of the issue and public awareness of its importance? Communicating about climate change has long focused on the environmental impact and scientific research related to increasing temperatures—melting ice caps, helpless polar bears, and a magnitude of data. While this narrative has motivated a small fraction of Americans to engage in the issue, the environmental focus has also contributed to polarized views about climate science, responsibility for mitigation or adaptation, and allocation of resources.[3]

Part of the disconnect also stems from the scale of climate change. As a global issue, climate change is simply too overwhelming and abstract for many people. Given the many immediately pressing and tangible issues that are competing for our attention on a day-to-day basis, climate change is an issue that tends to land outside our frame of reference. It is distant in space (not happening here), time (not happening now), and human relevance (not happening to me or my community). While this is all factually inaccurate, communicating about climate change needs to acknowledge that this **is** the frame of reference for many of our stakeholders.[4]

It's time for a new, more effective narrative—one that puts health and people at the center.

It's time for a new, more effective narrative—one that puts health and people at the center. Public health professionals are well positioned to shape this narrative and lay the foundation for a healthier, more resilient way forward. Research demonstrates that public health professionals are trusted messengers, especially when it comes to sharing information about health and climate. They also have the potential to motivate a large and diverse population. This combination of trust and reach provides a unique opportunity for health professionals to craft their communication efforts around climate change in a way that leverages their leadership, expands awareness, and helps protect the health of current and future generations.[5]

Recognizing Awareness and Attitude Challenges: The Six Americas

Climate change is a topic rife with emotion and politics. When communicating, there is no such thing as "the general public."[6] Researchers from the Yale Project on Climate Change Communication and George Mason University Center for Climate Change Communication have identified six distinct American audience segments for climate change communication. These audience segments are referred to as "Global Warming's Six Americas."[7] The researchers from these two organizations conduct surveys periodically to better understand current and previous viewpoints about climate change as well as events that may impact climate beliefs and attitudes.

The Six Americas are arranged on a spectrum of concern and engagement, ranging from *Alarmed* (those with the highest concern about climate change and who are most supportive of actions to mitigate the threat) to *Dismissive* (those who are convinced that climate change is not occurring and actively oppose efforts to reduce greenhouse gas emissions).

The greatest opportunity for building stakeholder understanding and engagement is in communicating with the segments that fall between these extremes: individuals who are categorized as *Concerned, Cautious, Disengaged*, or *Doubtful*. Reaching audiences in these four middle segments—currently comprising 73% of the American population—begins with understanding their diverse perspectives and requires tailoring simple, positive messages.[6,7]

Message Strategy: Put People and Health First

Tailoring messages begins with ***framing***. Framing is a communications process that allows the communicator to effectively engage with the stakeholder by linking key messages with deeply held values and beliefs. Intentionally communicating about climate change as a human health problem, rather than an environmental problem, has the potential to engage a much broader cross-section of the American public because health and well-being are broadly shared values. Maintaining this focus on people and health holds the narrative at a more familiar level, which encourages stakeholders to make relevant connections and engage in the issue.[3,5]

Key messaging will be nuanced from one stakeholder to the next, but in general it is important to start the narrative with a focus on people before moving to climate—not the other way around. Tying key messages back to people throughout the narrative builds on the trust people have in public health professionals and can motivate collective action.

Message Strategy: Timing and Sources: Early and Often, Emphasize Trusted Voices

The process of effective communication should consider communication frequency as well as who is delivering the message. While there is no single "right" answer about the number of times a stakeholder needs to hear a message before it resonates, it is generally accepted that messages are more effective when repeated by trusted sources. Ed Maibach, of the George Mason University Center for Climate Change Communication, underscored this point during a panel discussion at the 2017 Climate & Health Meeting when he noted that, *"Every major public health victory of the last century has had effective communication at its heart … effective public health communication looks like simple, clear messages, repeated often, through a variety of trusted voices."*[4]

"…effective public health communication looks like simple, clear messages, repeated often, through a variety of trusted voices."

When it comes to health information, Americans trust health professionals more than any other source. Health professionals also have an ethical obligation to help prepare the public for health risks associated with both routine and catastrophic harm. As the trusted experts on human health and well-being, health professionals are uniquely poised to enhance public understanding of the full scope of climate change and empower communities to participate in collective action.[4,5]

Getting bogged down in sharing too many statistics or numbers can cause people to tune out. Crafting a health and climate narrative that includes one or two facts from a trusted source—such as the Centers for Disease Control and Prevention or the American Public Health Association—and finding ways to share key points early and often have the most impact.[8]

Message Strategy: Connect on Common Values, Localize the Impact

People generally think of climate change in geographically and temporally distant terms, which reduces their concern about it and motivation to address it.[3] When possible, data and case studies from local communities, the state, or the region instead of (or in addition to) national and global data are more compelling. When the climate change narrative focuses on a local perspective, incorporating information that relates to daily life, people are more motivated to engage and respond more favorably.

Using community-based messages increases an individual's sense of efficacy and appealing to American values sets the stage for a less polarizing conversation. Commonly shared American values-based messages that draw personal connections to climate and motivate support for climate solutions include: fairness and prosperity; hard work and innovation; family, children, and caring; and freedom, independence and opportunity.[9]

Examples of Framing Your Message About Climate Change

1. Put People and Health First

- *Healthy people and healthy communities require clean air and water.*
- *Each breath we take should be a healthy one and caring for ourselves means caring for our climate.*
- *Some people are more at risk for the health impacts of climate change. Our work to stop pollution* [greenhouse gas pollution is a major cause of climate change] *can help people in our community live longer, healthier lives.*

2. Use Trusted Voices

- *According to the American Lung Association, the toxic chemicals in the air we breathe are affecting the health of nearly half of all Americans.*
- *We all have a variety of pressing daily concerns that compete for our time, but when the American Heart Association tells us that toxic pollution is in the air we breathe, we need to take steps toward a healthier future.*

3. Appeal to Common Values and Local Impact

- *Of all the things we'd love to leave our children and future generations, a healthy place for them to raise children of their own may be the most important.*
- *We've always been a "yes-we-can" kind of community and we have solved great challenges before. We can continue to lead the way with innovations that fuel a cleaner, safer, and healthier community for our families.*
- *We have a fundamental right to clean air and water. The power to shape a healthier future is in our hands.*

4. Be Positive and Empowering

- *We can leave our children and future generations a healthier community where the air is clean and the water is safe by using affordable solar and wind energy to power our homes and businesses.*
- *By walking and biking more often, we can improve our fitness, reduce pollution, and protect our families' health.*
- *Planting more trees around our homes and businesses can help clean the air we breathe, provide protective shade during heat waves, improve energy efficiency of our buildings, and naturally filter water for a cleaner, healthier community.*

Source: ecoAmerica. Let's Talk Health & Climate: Communication Guidance for Health Professionals. Climate for Health, Washington, D.C. Available from: https://ecoamerica.org/wp-content/uploads/2016/10/Lets_Talk_Health_and_Climate_eA.pdf.

Message Strategy: Stay Positive, Empower Change

When climate change information is communicated in a public health framework—especially messages about the positive health impacts of climate action—people from several audience segments experience hopeful emotions. When individuals feel hopeful, they often also have a greater sense of efficacy. They are more likely to believe that they have the capacity to take pro-environmental action, for themselves or their community, and that the outcome of their actions will be significant.

In order to achieve the hopeful emotions elicited by framing climate change as an important matter of public health, it is important to create and promote positive messages and quickly move to solutions.[5] The most engaging messaging provides the audience with clear choices for taking action. When possible, these choices should focus on the co-benefits of climate adaptation and mitigation and build from the available resources and expertise of stakeholders.[3]

Putting it All Together

For the well-being of our communities today and tomorrow, effective communication about health and climate should be a priority for all health professionals. Build from the tips and examples shared in this article to stay on the front lines of caring for our communities and making a difference in your community's health and climate. The following is just one example of how to put all the key message pieces together. Let this example inspire you to develop your own health and climate narrative:

The health of our families matters. When the American Lung Association tells us that toxic pollution in the air we breathe is affecting the health of nearly half of all Americans, we need new solutions. Kids seem to carry inhalers almost as often as lunch boxes. Seniors are stuck inside when weather shifts dramatically to extreme heat or freezing cold.

Thankfully, we have a plan for a healthier future. We can move away from the dirty fuels that make us sick and shift toward safe, clean energy, like wind and solar. Each breath we take should be a healthy one. We can walk or bike more often to improve our fitness while cutting down on pollution. And we can make our cities more sustainable so that we can live our best lives. Let's address this problem now, because caring for ourselves means caring for our climate.[5]

For More Information

The following organizations and articles provide more information on climate change communication resources:

- EcoAmerica, https://ecoamerica.org. The examples of climate change messages provided throughout this article were adapted from ecoAmerica's publication on communicating climate change, available from https://ecoamerica.org/wp-content/uploads/2016/10/Lets_Talk_Health_and_Climate_eA.pdf.
- George Mason University Center for Climate Change Communication, www.climatechangecommunication.org.
- Yale Program on Climate Communication, http://climatecommunication.yale.edu.
- Maibach EW, Roser-Renouf C, Leiserowitz A. Communication and marketing as climate change–intervention assets: a public health perspective. Am J Prev Med 2008;35(5):488–500. Available from: http://www.ajpmonline.org/article/S0749-3797(08)00681-8/pdf.

References

1. Watts N, Adger WN, Agnolucci P, et al. Health and climate change: policy responses to protect public health. Lancet 2015;386:1861-914. Available from: www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(15)60854-6.pdf.
2. Leiserowitz A, Maibach E, Roser-Renouf C, et al. Public perceptions of the health consequences of global warming. Yale University and George Mason University. Yale Project on Climate Change Communication. 2014. Available from: http://climatecommunication.yale.edu/wp-content/uploads/2014/12/Global-Warming-Public-Health-October_2014_FINAL-1.pdf.
3. Maibach E, Nisbet M, Weather M. Conveying the human implications of climate change: a climate change communication primer for public health professionals. Fairfax, VA: George Mason University Center for Climate Change Communication. 2011. Available from: www.climatechangecommunication.org/all/conveying-the-human-implications-of-climate-change/.
4. Maibach, E. Communicating the climate-health connection. Presented at Climate & Health Meeting; 2017 February 16; Atlanta GA. Available from: https://Secure3.Convio.Net/Apha/Site/Spagenavigator/YocchclimatemeetingreplayregistrationRegistration.html.
5. ecoAmerica. Let's talk health and climate: communication guidance for health professionals. [Internet]. Washington, DC: Climate for Health. 2016.
6. Roser-Renouf C. Environmental health communications: message strategies from a climate change perspective. Presented at Partnerships for Environmental Health; 2012 March 12; Washington DC. Available from: https://www.niehs.nih.gov/news/assets/docs_a_e/environmental_health_communication_message_strategies_from_a_climate_change_perspective_508.pdf.
7. Roser-Renouf C, Maibach E, Leiserowitz A. Global warming's six Americas and the election, 2016. Yale University and George Mason University. [Internet]. New Haven, CT: Yale Program on Climate Change Communication;2016. Available from: http://climatecommunication.yale.edu/publications/six-americas-2016-election/.
8. ecoAmerica. 15 Steps to create effective climate communications. [Internet]. Washington, DC: Climate for Health;2016. Available from: https://ecoamerica.org/wp-content/uploads/2016/06/ecoAmerica-15-Steps-To-Create-Effective-Climate-Communications.pdf.
9. ecoAmerica, Lake Research Partners, Krygsman K, et al. Let's talk climate: messages to motivate Americans. [Internet]. Washington, DC: Climate for Health;2015. Available from: https://ecoamerica.org/wp-content/uploads/2015/11/eA-lets-talk-climate.pdf.

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Adaptation Efforts in US Communities

Diverse communities in the US—from Flagstaff to Cleveland—are implementing innovative approaches to protect residents from the impacts of climate change, according to a 2017 report, *Climate Adaptation: The State of Practice in U.S. Communities.* The report reflects findings from the first study to examine actions that communities have taken to address climate-change threats like flooding, heat waves, wildfires and intense storms. The study found more municipalities are preparing for climate risks than is conventionally believed and that many of those actions support community goals and values. In addition to reporting current efforts, the report details the motivations for actions and how communities have moved beyond planning to action. It includes case studies of 17 communities in the US. Despite the progress, the authors conclude that more work is needed to address the many climate risks in the US. The report is at http://www.georgetownclimate.org/files/report/climate-adaptation-the-state-of-practice-in-us-communities-full-report.pdf.

Commentary:
It's Time to Talk about Population Control

by Wendy L. Hellerstedt, MPH, PhD

The associations between population growth, economic development, environmental quality and climate change are clear. Climate change is a direct consequence of fossil fuel use. The more people, the greater the burden of energy needs on the Earth. Climate change and overpopulation thus threaten the health of environments and people. The threats may disproportionately fall on socially vulnerable individuals who do not have access to protective sanitary, energy, and health infrastructures.

Public health and global health experts recognize that perhaps half of the world's births are unintended and that access to contraception and reproductive health services is not only a health issue, but a gender and social equity concern.[1] Public health professionals, however, have not promoted one the co-benefits of individual reproductive control: climate change mitigation.

The Global Population is Growing

Because of huge population growth in the 20th Century, the Earth's population is expected to be ten times larger in 2050 (about 9.7 billion) than it was for most of the 19th Century, when there were about 1 billion people.[2] Global population and rates of fertility mask regional differences: population size and birth rates are very high in some of the lowest-income areas of the world, like sub-Saharan Africa, and are low in higher-income countries, especially those in Europe.

China and India are the two most populated countries, representing 19% and 18% of the world's population, respectively.[2] Both of those countries are rapidly industrializing. They are also rapidly polluting and experiencing severe weather events. Among the most populated nations, one is in Africa (Nigeria), five are in Asia (Bangladesh, China, India, Indonesia, Pakistan), one is in North America (the US), and one is in Europe (Russia).[2]

Half of the world's *population growth* between 2015-2050 will be in nine countries, only one of which is a high-income country. The nine countries, in order of projected growth, are: India, Nigeria, Pakistan, Democratic Republic of the Congo, Ethiopia, the United Republic of Tanzania, the US, Indonesia and Uganda.[2]

It is not only fertility rates that influence population size and growth. Mortality is also important. The present demographic transition—a shift from high mortality and high fertility to low mortality and low fertility—has resulted in global population aging and urbanization.[3]

Environmental Consequences of Population Growth

Bradshaw, et al. evaluated the environmental impact of countries and concluded that there were three main factors that explained environmental damage. The absolute wealth of a country was the primary driver. Population size was second in importance. Poor governance was the third factor, with a much smaller impact than the first two contributors.[4]

The associations of population size with environmental quality and climate change are clear. With more people, there are increased demands for fuel, food, land, and water. Higher demands contribute to climate change. Climate change and higher demands interact to increase air pollution, soil exhaustion, crop failures, land degradation, water depletion and contamination, and the loss of animal and plant species.

More people also results in increased urbanization, which increases the risks for crowding-related infectious diseases, as well as violence-related health and social outcomes. Population size and fertility also contribute to social inequities. Higher fertility—in all parts of the world—disproportionately falls on the most socially disadvantaged people, thus entrenching them in poverty and limiting educational and social opportunities. Fertility is also higher in lower-resource areas.

Low-income countries have not contributed as much to climate change as high-income countries. However, their economic development, coupled with their large population size and growth, increases their demands for energy and resources. Further, many lower-income countries do not exercise regulatory controls on businesses, so as they industrialize they are replicating the Industrial Revolution experiences of higher-income countries by polluting their local environments. Unfortunately, many low-income countries do not have the sanitation or health infrastructures to address environmental and climate-related health conditions. Because fertility rates are highest in low-income countries, effective population control can contribute to development efforts: smaller family size should improve individual access to economic resources and opportunities as well as reduce resource, environmental, and infrastructure demands.

China and India are the two most populated countries, representing 19% and 18% of the world's population, respectively.[2] Both of those countries are rapidly industrializing. They are also rapidly polluting and experiencing severe weather events.

Another consequence of high fertility rates is high maternal and child health risks. For example, in many low-income countries a significant contributor to maternal mortality is deaths from illegal (and therefore unsafe) abortion. The facts that abortion deaths make a significant contribution to maternal mortality rates—and that women are willing to risk their lives to avoid an unwanted birth—underscore the dangers of unintended pregnancy and the depth of anguish associated with it. Those facts also make clear that the equitable distribution of, and universal access to, reproductive health and family planning services have benefits beyond climate change mitigation.

A Public Health Response Is Needed

Demographers have dominated the scholarly discussions about population growth. They often focus on the population proportions of elderly pensioners and young workers, raising concerns about how the growing financial and care needs of the former will be met in countries where fertility rates are low. Narrow demographic concerns have pushed some countries to launch ill-advised and stigmatizing pro-natalist campaigns. Italy, which has had many pro-natalist policy failures since Mussolini, had another failed initiative in 2016 to address its low fertility rates. It used promotional messages like, *"Beauty has no age limit. Fertility does."* The messages created a furor, were denounced as sexist and ageist, and were withdrawn.

The issues of population, public health, economic development, and climate change have generally been explored individually. It is time to consider how they interact. Even the Intergovernmental Panel on Climate Change's 2014 report barely mentioned population as a driver of climate change or population control as a form of mitigation.[5] Public health professionals must develop their expertise in these issues, especially in population control. Public health concerns about population control and growth have been indirect at best, focusing on reducing unintended pregnancy, universal access to safe and effective contraception, and, to some degree, the association between reproductive control and gender equity.

Population control is complex and controversial. There are cultural mores about parenting and even about optimal family size that public health has been reluctant to acknowledge, let alone address. But public health professionals have the capacity, and the history, to take on tough issues. For example, to benefit population health, public health professionals have led, or supported, the promotion of individual behavioral change programs (e.g., anti-smoking education) and policies (e.g., seat belt laws, water fluoridation). Public health professionals need to overcome their reluctance to influence individual decision-making about family formation by framing it from an environmental or climate-change perspective. As the burdens on the Earth persist, one could even argue that family formation decisions are ethical decisions because of their social impact.

Public health reticence may be, in part, informed by the dominance of demographers in population growth debates. They have articulated the arguments and have defined the essence of population issues. Demographers have been especially vocal about how important young workers are to an economy, but the translation of this view at the national policy level has rarely promoted the most obvious solution: liberal immigration laws. National policy has often turned to encouraging the fertility of its citizens, even though many immigrants from lower-income countries are young, willing to work, and want to leave environments that cannot support them. The nasty truth may be that higher-income countries with low fertility rates do not want to increase the number of young

citizens through immigration.

Public health professionals can expand the population discussion to a global scale. The Earth is overpopulated, even though individual countries or regions have varying levels of overpopulation and disproportionately suffer from the consequences. Even countries that have policies to increase birth rates for economic reasons still have crowded cities, unemployment, and pollution—woes that come with too many people. And, as the number of people on Earth increases, the health of all nations suffers, and will continue to suffer, because of our inter-connectedness. Food availability, pollution—even the effects of civil unrest that can come from overpopulation or climate change—transcend regional and national boundaries.

There is a possibility that, in the near future, countries will have to confront overpopulation to address climate concerns. Some may do so with little regard for civil liberties. Population restriction policies have rarely been benign and they continue to happen, sometimes under the radar of most of the world. For example, it was recently revealed that more than 260,000 mostly poor and indigenous women in Peru had involuntary tubal ligation operations between 1996-2000. Public health professionals have an ethical obligation to raise the issue of population control measures *now* and be part of national and global initiatives that most likely will occur to curb population growth.

Public health professionals can easily apply several public health principles to population control measures, especially those related to *prevention* (e.g., ensure safe and equitable access to contraception, as well as comprehensive reproductive health education, so population control efforts meet climate-related mitigation goals), *preparedness* (e.g., anticipate contraceptive needs and advocate for policies and programs that meet those needs), and *risk management* (e.g., identify and protect people from coercive population control policies). Further, public health professionals can address the rarely discussed, but universally prevalent, stigma against individuals who choose not to bear children. They can also effectively emphasize the co-benefits of being volitionally child-free to individuals, including (1) increased opportunities to pursue livelihoods and avocations; (2) more time to meet obligations to family, friends, and community; (3) freedom from the economic costs of child rearing; and (4) avoidance of parenting-related stressors.

Public health practice is also influenced by three perspectives—utilitarianism, liberalism, and communitarianism—each of which provides rationale for supporting population control policies and programs. In terms of utilitarianism, the net sum of human well-being, especially when considering future generations, is to avoid excessive population because it will lead to insufficient resources, climate crises, and mass suffering. Liberalism demands a focus on equitable population control policies and universal access to contraceptives and reproductive health education and services. A communitarian argument is that overpopulation, and its climate change consequences, threaten the social order directly and indirectly through civil unrest, forced migration, and community and natural resource devastation.

Climate change has—and is—happening. Future projections suggest dire consequences. Overpopulation has happened—and may continue to happen. It is likely only a matter of time before population control becomes a matter for political discourse and, perhaps, policy. It is critical that public health perspectives inform these inevitable population control discussions. Public health professionals can do so by continuing their work to ensure contraceptive and family planning programs and access. And they can begin to stress the climate and individual co-benefits of reproductive control; reduce the stigma associated with not parenting; and educate the public about the connections between population size, fossil fuel use, and their environmental and climate consequences.

For More Information

1. ***Population Matters*** is an organization that seeks sustainable solutions in the context of overpopulation. It produces a newsletter, a journal, and many educational materials. It is available from: http://www.populationmatters.org/issues-solutions/population.
2. ***Population Connection*** is a grassroots organization, formerly known as *Zero Population Growth.* Its website has a magazine and several articles about how population growth affects the well-being of humans (e.g., health, urbanization, gender equality). It is available from: http://www.population-connection.org/us/.

References

1. World Health Organization. MDG5: improve maternal health. Available from: http://www.who.int/topics/millennium_development_goals/maternal_health/en/.
2. United Nations Department of Economic and Social Affairs. The world population prospects: 2015 revision. [Internet]. 2015. Available from: http://www.un.org/en/development/desa/publications/world-population-prospects-2015-revision.html.
3. Stephenson J, Crane SF, Levy C, et al. Population, development, and climate change: links and effects on human health. Lancet 2013;382(9905):1665-73. Available from: http://z.umn.edu/stephenson.
4. Bradshaw CJ, Giam X, Sodhi NS. Evaluating the relative environmental impact of countries. PLoS One 2010;5(5):e10440. Available from: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0010440.
5. Intergovernmental Panel on Climate Change. Fifth assessment report. [Internet]. 2014. Available from: http://ipcc.ch/report/ar5/.
6. Frumkin H, Hess J, Luber G, et al. Climate change: the public health response. Am J Public Health;2008:98(3):435-45. Available from: http://z.umn.edu/frumkin.

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Eamon Flynn & Kathleen Thiede Call: Teaching Health Impact Assessments—A New Tool to Promote Health Equity (PubH 7220) at the University of Minnesota

Our course will introduce students to Health Impact Assessment (HIA) methodology and practice. HIA is a new six-step tool used to inform decisions in non-health sectors.

Under this framework, we encourage students to apply their knowledge and skills to uncover the potential health impacts of a proposed policy, program, or plan decision.

Through class and small-group discussions, case studies, and HIA-specific exercises, we will explore the practical application of HIA to advance Health in All Policies in transportation, education, criminal justice, and urban planning sectors.

Zobeida Bonilla: Teaching Foundations of Maternal and Child Health Leadership (PubH 6630 and PubH 6655) at the University of Minnesota

In the Foundations course I strive to provide students with the depth and breadth of the field of maternal and child health (MCH) in the US. We ground ourselves in the rich historical evolution of MCH in this country.

We study the early and current MCH leaders and advocates that have pushed for legislative and programmatic change that have resulted in the creation of new knowledge, programs, policies and systems to address the needs of mothers, infants, children, families, and communities.

We take a lifecourse approach to learning about MCH populations and, through interactive learning activities, I ask students to assess the social, cultural, economic and political factors that contribute to heath inequities.

Throughout the course, I ask students to reflect on their leadership style and social positioning as MCH future practitioners as they cultivate their own leadership skills in public health.

Theresa Osypuk: Teaching Urban Health & Social Policy (PubH 6000) at the University of Minnesota

In my course, we apply a social epidemiologic, interdisciplinary perspective to understand urban health.

We examine policies operating outside of the health sector that may improve urban population health and reduce health inequities by improving social determinants of health.

In this translational social epidemiology course, we delve into the expected US population trends for the next 50 years by key social strata (demography of inequality).

We discuss the social epidemiology of issues with which urban areas struggle (including concentration of poverty, residential segregation, educational inequality, unemployment), and the theories guiding urban health and social epidemiology scholarship.

We also examine social and economic policies across different sectors (outside of the health sector) with evidence to reduce health disparities and improve health in urban areas (a "health in all policies" approach; for example, preschool education policies, income policy, housing policy, neighborhood revitalization, and policing policies).

Resources: Selected Climate Change Reports and Publications

Climate Change and Health

American College of Physicians. The ACP released *Climate Change and Health: A Position Paper of the American College of Physicians* (ACP) in 2016, which addresses how physicians might improve health and prevent negative environmental outcomes.
http://annals.org/aim/article/2513976/climate-change-health-position-paper-american-college-physicians

American Public Health Association (APHA). APHA has some resources about public health and climate change, including a social media toolkit.
https://www.apha.org/topics-and-issues/climate-change

Center for Climate Change and Health. The Center functions as a hub for the a climate change Community of Practice in the Public Health Institute (PHI). Its materials are for community leaders, scientists, policymakers, health care providers, and the general public. It recently produced *A Physician's Guide to Climate Change, Health and Equity.*
http://climatehealthconnect.org/resources/physicians-guide-climate-change-health-equity

Climate and Health Program, Centers for Disease Control and Prevention (CDC). The Climate and Health Program recently released two technical guidance documents to help the public health community anticipate the future health impacts of climate change: (1) *Projecting Climate-Related Disease Burden: A Guide for Health Departments* (an overview of the process of establishing exposure-response relationships and developing scenario-based projections), at https://www.cdc.gov/climateandhealth/pubs/projectingclimaterelateddiseaseburden1_508.pdf; and (2) a companion piece, *Projecting Climate-Related Disease Burden: A Case Study on Methods for Projecting Respiratory Health Impacts*.
https://www.cdc.gov/climateandhealth

Environmental Protection Agency (EPA). The EPA has many climate change resources, including the brochure, *Climate Change and Children's Health* that describes, *"the effects that climate change has on children's health, differentiated from its effects on adults,"* and offers solutions for climate change prevention. The brochure is at https://www.epa.gov/sites/production/files/2014-05/documents/ochp_climate_brochure.pdf. The EPA (and the CDC) also recently updated a guidebook for the public on extreme heat, entitled, *Climate Change and Extreme Heat: What You Can Do to Prepare.*
It is available at https://www.epa.gov/climatechange/extreme-heat-guidebook.
https://www.epa.gov/climatechange

Health Professionals for a Healthy Climate. The purpose of this organization is to help health professionals understand the "*nature and dangers posed to public health by the continued dependence of our societies on fossil fuels as an energy source."* It creates curricula for health professionals and supports environmentally friendly legislation.
http://www.hpforhc.org

Medical Society Consortium on Climate and Health. The Consortium is made up of nine medical associations representing more than half of the physicians in the US in specialty areas including pediatrics, obstetrics and gynecology, preventive medicine, and asthma, allergies, and immunology. The mission of the consortium is to inform the public and policy makers about the harmful health effects of climate change and preventive measures. In 2017, it published a 28-page publication, *Medical Alert! A 2017 Report that Provides Facts and Physicians' Perspectives about Health Conditions Related to Climate Change.* The report covers many illnesses, providing a brief fact-based summary of risk and a physician's commentary.
http://medsocietiesforclimatehealth.org/wp-content/uploads/2017/03/medical_alert.pdf.

National Institute of Environmental Health Sciences (NIEHS). The NIEHS page, *Climate Change and Children's Health,* covers the effects of climate change on children. Included on the page is the report, *Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,* along with an accompanying video recording of the July 2014 meeting, *Consultation on the Effects of Climate Change on Children's Health*.
http://www.niehs.nih.gov/research/programs/geh/climatechange/policy_roundup/index.cfm

World Health Organization (WHO). The WHO has resources about global climate change and health, including exhaustive scientific reviews and reports and news updates.
http://www.who.int/mediacentre/factsheets/fs266/en/

Climate Change Research and General Information

American Association for the Advancement of Science (AAS) Climate Science Panel. *What We Know*, a report published by the AAS Climate Science Panel, summarizes the current research about the causes, risks, and potential responses towards climate change.
http://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf

Building Resilience Against Climate Effects (BRACE)-Illinois. This website provides resources for public health professionals, community organizers, and planners about climate change and sustainability initiatives and public health programs efforts. It also has reports, videos, and articles, describing such things as the health impacts of climate change, Chicago's climate action plan and Illinois' climate and health profile. In addition, it provides a *Summer Heat Toolkit* to help professionals protect citizens from extreme heat.
https://braceillinois.uic.edu

Cooperative Institute for Research in Environmental Sciences (CIRES). CIRES is a partnership of the National Oceanic and Atmospheric Administration (NOAA) and the University of Colorado Boulder that specializes in weather and climate, changes at Earth's poles, air quality and atmospheric chemistry, water resources, and solid Earth sciences.
http://www.cires.colorado.edu/about

Earthstat. EarthStat.org curates geographic data sets with the purpose of solving the grand challenge of feeding a growing global population while reducing agriculture's impact on the environment. The data sets on EarthStat allow users to map the distribution of crops globally, analyze the impact of climate change on crop yields, understand the impacts of fertilizer and manure use, and much more.
http://environment.umn.edu/engage/earthstat

Environmental Protection Agency (EPA). The EPA's has many climate change resources that explain the science of climate change as well as its potential effects. It also produces reports on specific aspects of climate change. For example, in 2016 it released an 45-minute online training module, *Understanding Climate Change Impacts on Water Resources*. It is intended to increase water resource professionals' understanding of the causes of climate changes, its potential impacts on water resources, and the challenges that water resource professionals face. The module is at https://www.epa.gov/watershedacademy/understanding-climate-change-impacts-water-resources.
https://www.epa.gov/climatechange

Food Matters. Food Matters, a University of Minnesota collaboration between scientists and designers, addresses food- and climate-related topics in visually appealing and interactive reports that are perfect to download or share via social media.
http://environment.umn.edu/engage/environment-reports

Institute on the Environment (IonE). The Institute on the Environment at the U of MN is a collaborative between U of MN experts and others who are dedicated to sustainable solutions. Its website has many resources and provides access to a bi-weekly electronic newsletter. Its YouTube channel has webinars and short videos that address climate change, water conservation, and other related topics. IonE also produces a publication, *Ensia,* that presents new perspectives on environmental challenges and solutions for a global audience. And, along with the U of MN's Law School, the IonE supports the Energy Transition Lab. The Lab is focused on ways to develop new energy policy pathways, institutions, and regulations.
Website: **http://environment.umn.edu**
YouTube: **https://www.youtube.com/channel/UCXzMUZRZtBE0GtF1R-COWMbw**
Ensia: **http://ensia.com**
Energy Transition Lab: **http://energy-transition.umn.edu**

Intergovernmental Panel on Climate Change (IPCC). The IPCC is a scientific body under the auspices of the United Nations. It reviews and assesses scientific, technical and socio-economic information produced worldwide that is relevant to the understanding of climate change.
https://www.ipcc.ch/index.htm

The Minnesota Climate and Health Program, Minnesota Department of Health (MDH). The MDH has a comprehensive website about climate change topics, including videos and training materials on many specific topics (e.g., climate-related food insecurity). MDH also published an excellent report in 2015 on climate change in Minnesota, future projections, and health at http://www.health.state.mn.us/divs/climatechange/docs/mnprofile2015.pdf.
http://www.health.state.mn.us/divs/climatechange/

Resources: Selected Climate Change Reports and Publications

- **Minnesota Environmental Quality Board.** The 2007 Next Generation Energy Act requires Minnesota to cut its annual emissions of greenhouse gases by 80% between 2005 and 2050. The Minnesota Environmental Quality Board published *Climate Solutions and Economic Opportunities: A Foundation for Minnesota State Climate Action Planning* in July 2016. This report focuses on near-term emissions reductions between the present and 2030. It includes analysis and discussion of the reduction options.
  https://www.eqb.state.mn.us/sites/default/files/documents/CSEO_EQB.pdf

- **Nature Conservancy.** The mission of the Conservancy is to *"conserve the lands and waters on which all life depends."* Of note is its carbon footprint calculator, which helps consumers estimate how much carbon dioxide and other greenhouse gases they use each year.
  http://www.nature.org/ourinitiatives/urgentissues/global-warming-climate-change/index.htm

- **Population Matters.** Population Matters is focused on finding ways for humans to live sustainably in spite of our ever-growing population. *Population Matters* publishes a scientific journal, *The Journal of Population and Sustainability,* a monthly eNewsletter, books related to population and sustainability, lists of datasets and infographics, and other resources.
  http://www.populationmatters.org/issues-solutions/population

- **The Royal Society and the US National Academy of Sciences** produced several educational tools, including written materials and several videos that describe the basic science of climate change.
  https://royalsociety.org/topics-policy/projects/climate-change-evidence-causes/

- **University of Minnesota's Expeditions in Computing: Understanding Climate Change.** The project's website provides methodological articles, access to data software and tools, replication of key presentations made by its investigators, and many other resources for individuals interested in methods to better understand climate change.
  http://climatechange.cs.umn.edu/index.php

- **US Forest Service Climate Change Resource Center (CCRC).** The CCRC offers educational modules, tools, and briefings about how climate change is affecting forests and other ecosystems and effective responses.
  http://www.fs.usda.gov/ccrc

- **US Global Change Research Program (USGCRP).** The USGCRP was established by the Presidential Initiative in 1989 and mandated by Congress in 1990 to "*assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."* USGCRP conducts state-of-the-art research to understand the interactive processes that influence the total Earth system—which includes the atmosphere, oceans, land, ice, ecosystems, and people. Its website has a large resources library. In 2016 USGCRP produced an assessment of a growing public health threat, *Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, which can be found at
  https://health2016.globalchange.gov.
  http://www.globalchange.gov/about

- **Wisconsin Department of Health Services.** This agency has several initiatives and a website for professional and public education. Among its resources are a toolkit for professionals who address climate change; factsheets, infographs, articles and reports about extreme weather (with a focus on Wisconsin and the Midwest) and climate and health; a full description of Wisconsin's innovative heat index efforts; and surveillance briefs.
  https://www.dhs.wisconsin.gov/climate/index.htm

- **Woods Hole Research Center.** Woods Hole Research Center is an independent research institute where scientists investigatethe causes and effects of climate change to identify and implement opportunities forconservation, restoration, and economic development around the world. Its projects include those related to the arctic permafrost, ecosystems and climate change, the green economy, global carbon use, sustainable landscapes, and forest monitoring.
  http://whrc.org/publications-data/understanding-climate-change-a-primer

- **World Metereologic Organisation (WMO).** WMO, a specialized agency of the United Nations, is *"…dedicated to international cooperation and coordination on the state and behaviour of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources."* WMO has many resources about climate change, including a global climate observing system, climate predictions, and a capacity developing program for extreme weather events.
  https://public.wmo.int/en/our-mandate/climateh

- **World Resources Institute (WRI).** WRI is an excellent source of open-access, peer-reviewed publications about climate change, energy, agriculture, sustainable development, water, and other environmental topics. WRI also includes publications on policies and practices concerning the environment from an economics and business lens.
  http://www.wri.org/about

- **Yale Environment 360.** This is *"… an online magazine offering opinion, analysis, reporting, and debate on global environmental issues. We feature original articles by scientists, journalists, environmentalists, academics, policy makers, and business people, as well as multimedia content and a daily digest of major environmental news."*
  http://e360.yale.edu

Climate Change Programs and Policy

- **350.** 350 is an organization that works toward grassroots development of climate justice programs and policies. It provides a toolkit for local climate resilience leaders and grassroots organizers.
  https://350.org/

- **Center for Climate and Energy Solutions (C2ES).** C2ES uses policy to promote practical solutions to climate change, including reducing greenhouse gas emissions, promoting clean energy, and creating better responses to climate change through policy.
  http://www.c2es.org

- **Climate Change, Agriculture, and Food Security (CCAFS).** CCAFS is a collaboration of CGIAR, a global agricultural research partnership, and works to address sustainable agriculture in a changing climate. The website offers policy briefs, reports, toolkits, maps, and interactive datasets.
  https://ccafs.cgiar.org/about-us#.WORl4UJUyiJ

- **Citizen's Climate Engagement Network.** The Citizens' Climate Engagement Network is a global framework to support and expand direct citizen and stakeholder engagement in the intergovernmental climate negotiating process.
  https://engage4climate.org/about

- **Georgetown Climate Center.** The Georgetown Climate Center works with government officials, academics, and stakeholders to inform policies that reduce carbon pollution, support clean transportation, and help communities across the US adapt to climate change. The Center's website provides toolkits, reports, databases, and research on selected topics.
  http://www.georgetownclimate.org

- **Population Connection.** This grassroots organization was formerly known as *Zero Population Growth.* Its aim is to be an American voice for population stability and to ensure that every woman in the world has the ability to end or delay childbearing, according to her wishes. It has a magazine and several articles about how population growth affects the well being of humans (e.g., health, urbanization, gender equality).
  http://www.populationconnection.org/us/

- **Rockefeller Foundation.** The Foundation supports many global initiatives on climate change, globalization, natural resources, and sustainability and offers blog posts and reports.
  https://www.rockefellerfoundation.org/our-work/topics/climate-change

- **United Nations (UN).** The UN has a website with recent climate change news and resources about global efforts. It also has social media that can be accessed through the website.
  http://www.un.org/sustainabledevelopment/climatechange/

- **United Nations' Paris Agreement on Climate Change.** The Paris Agreement brought together many nations (including the greatest polluters, China, India, and the US) to combat climate change and adapt to its effects. Its central aim is to *"…strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius."*
  http://unfccc.int/paris_agreement/items/9485.php

The University of Minnesota's (UMN) Public Health Core Concepts Certificate Program

The UMN Public Health Core Concepts Certificate Program, designed for working public health or human service professionals, can be completed online.

Program participants learn the fundamentals of public health, including epidemiology, biostatistics, ethics, health management, social and behavioral sciences, and environmental health.

The Certificate Program may also be of interest to individuals who are considering applying to one of the UMN's Master of Public Health programs because all of the certificate courses may be transferred to that degree. Go to z.umn.edu/cccp for more information.

Jennifer Linde: Teaching Fundamentals of Social & Behavioral Science (PubH 6020) at the University of Minnesota

The overarching aim of this online course is for students get the big picture of how social sciences contribute to our broader understanding of public health: what do we know of behavior change, and how might we use that to influence population health? How do we apply knowledge from diverse disciplines (psychology, communications, community organizing, economics, law, and public policy) to elicit change from individuals and systems?

By choosing their own health topic to follow throughout the course, I hope that these questions come to life for students and spark interest in the interplay between individuals, environments, and health.

CEPH*-accredited Master of Public Health Degree

University of Minnesota, Maternal and Child Health Program sph.umn.edu/programs/mch

Our Maternal and Child Health (MCH) Master in Public Health (MPH) students come from a variety of backgrounds, but share a focus on social justice and public health principles. They assume leadership roles in nonprofits, research settings, public health agencies, and health care organizations.

MPH options in MCH at the University of Minnesota:

- **Advanced-standing:** 42-credit minimum MPH for individuals with an advanced degree or at least 3 years of experience in a MCH-related field. All students pay in-state tuition.**
- **Standard:** A 48-credit minimum MPH for individuals with no advanced degree and little or no professional experience in a MCH-related field**
- **Epidemiology emphasis:** A 48-credit minimum MPH that provides the same methods courses required for an Epidemiology MPH
- **Dual degrees:** in law or social work
- **Concentrations (for standard students):** in global health, policy, or health equity.

* *CEPH: Council on Education for Public Health*

***The advanced-standing and standard programs may be completed entirely online, in-person, or with a combination of online and in-person classes.*

Want to Train the Next Generation of MCH Professionals?

All MCH MPH students are required to complete a 120-hour field experience doing public health work (paid or unpaid). If you have a project that needs a talented student and you have a master's degree (or greater), consider becoming a preceptor. Learn more by visiting z.umn.edu/precept.

Find the Center for Leadership Education in MCH on Social Media

Please visit our Facebook page (facebook.com/MCHUMN) or follow us on Twitter (@umn_MCH), Instagram (umn_mch) or YouTube (umn_mch). We post news about public health research, programs, employment opportunities, policies, trainings, and events related to women's health, reproductive health, infant and child health, adolescent health, and the health of vulnerable populations. Our site may be of most interest to public health practitioners, policymakers, researchers, students, and graduates of our MCH Program.

Visit the Center's Website!

Wondering what's happening at the Center? Trying to find MCH-focused resources? Looking into our MCH MPH Program? Look no further than epi.umn.edu/mch.

Resources: In addition to *Healthy Generations*, you'll find our videos, fact sheets, and more at epi.umn.edu/mch/resources.

Publications: Access 15+ years worth of *Healthy Generations* covering topics ranging from early childhood, to reproductive and sexual health, to poverty and hunger.

eNewsletter Archives: You may already be getting one of our two newsletters every month weeks, but if you're a new subscriber, you may want to check out our archived newsletters.

Fact Sheets and Briefs: We have adolescent health QuickGuides, topical fact sheets, resources on the reproductive health of incarcerated women, and more.

Videos: This page now includes local radio show interviews and video from previous events, as well as interviews with MCH students (see "Student Spotlight" below).

Events: Did you know that we help organize more than 20 educational events and trainings every year? Link up to our Google calendar, or find out about our sponsored events on epi.umn.edu/mch/events.

Student Spotlight: We update our Student Spotlight approximately every 6 weeks, so check our homepage frequently to learn about the diverse work current MCH students are involved in.

Academics: Wondering what MCH students study? Want to know where students do their field experiences? Find out at epi.umn.edu/mch/academics.

Research: Want to make one stop to find out about MCH topics like children with special health care needs, pregnant women and recent mothers, families, and women's health? epi.umn.edu/mch/research contains research-based information on these topics (and more).

Social Media Feeds: Our homepage has our latest Facebook and Twitter posts, so you can be a part of the action, see job postings, learn about upcoming events, and get the latest MCH news all in one place.

Would You Consider Making a Gift to the Maternal and Child Health Fund?

Support our MPH students with a gift to our Maternal and Child Health fund. Your donation will go directly to support the tuition of students who are our future public health leaders!

Gifts of all sizes are welcome! We thank you for your generosity no matter the dollar amount. Visit z.umn.edu/mchsupport to make a difference in the lives of our students.

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Climate Change Conferences and Events

We have compiled a list of climate change-related conferences and events taking place nationally and internationally. This list—which can be found on our website at http://www.epi.umn.edu/mch/ccevents—provides dates, brief descriptions, and registration links for some of the many climate-focused events occurring in the coming year. The Center for Leadership Education in Maternal and Child Public Health (MCH) sponsors many MCH events and trainings throughout the year. Visit the Center's events calendar at www.epi.umn.edu/mch/events to learn more!

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