

ISSUE BRIEF

CLIMATE CHANGE AND HEALTH IN VIRGINIA

Have you noticed that Virginia summers have gotten hotter and stickier? Does it seem like allergy season is more intense? Is your home flooding more often than it used to?

It's not your imagination. Climate change is altering seasonal patterns, making our summers hotter, and fueling increased flooding from coastal storms, like Hurricane Sandy in 2012.¹ As a result, we face more heat-related illnesses, air quality issues, food and water contamination, traumatic injuries, threats to our mental health, and infectious diseases.² These threats will only get worse as big polluters continue to pump carbon from coal, oil, and natural gas into the air.

The good news is that we can protect ourselves from these impacts by moving to cleaner energy strategies and preparing more effectively for future disasters.³

EXTREME HEAT IS BAD FOR VIRGINIANS' HEALTH— AND COULD BECOME MORE DEADLY

Virginia summers are getting hotter—and could become downright dangerous in just a few decades. One way to define extreme heat is to look at maximum temperatures, which have climbed about 1 degree Fahrenheit in Virginia since 1895.⁴ The average national risk of death increases about 2.5 percent for every 1°F increase in the intensity of heat waves, according to one study of 43 American cities from 1987 to 2005.⁵

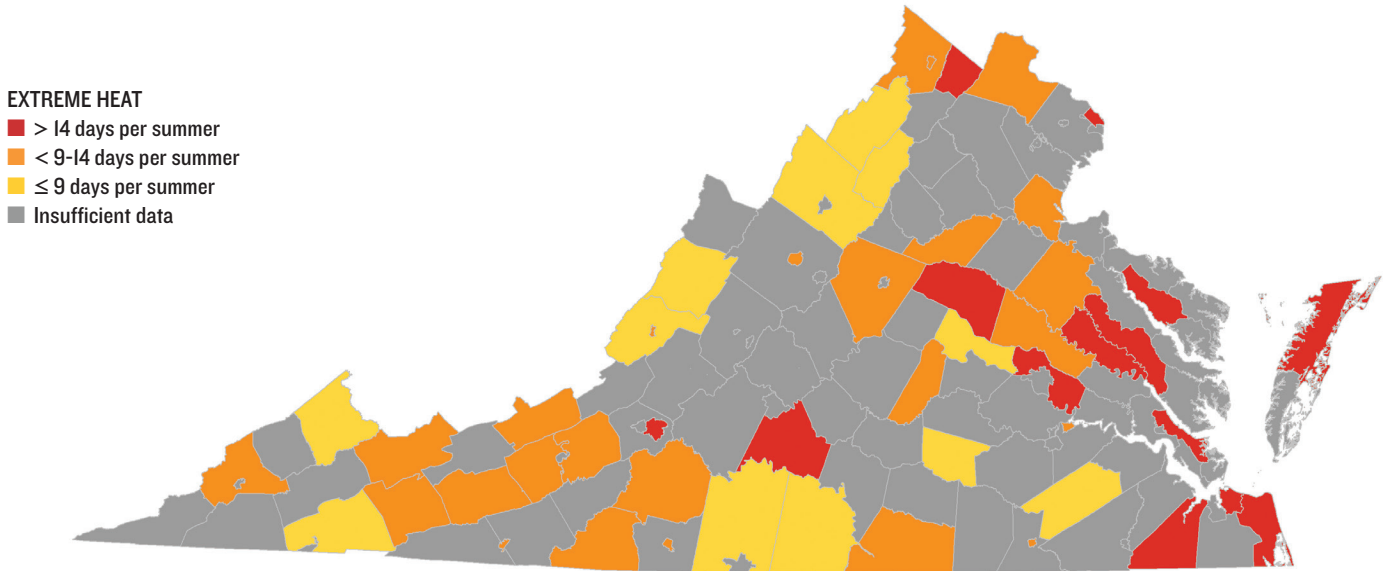
Daily summer highs at Richmond International Airport averaged 88.6°F in the past decade, compared with 85.6°F in the 1960s.⁶ From 2007 to 2016, 36 percent of Virginians lived in counties that experienced more than nine extreme heat days per year, more days than expected on the basis of local historical averages (Figure 1).⁷

Heat and humidity already pose a range of threats to Virginia residents, from minor illnesses like heat cramps to deadly conditions like heatstroke or heat-related heart attacks.⁸ In the summer of 2017, Virginia's emergency departments and urgent care clinics recorded 498 visits for heat-related issues over 10 days.⁹

The risk of heat-related illnesses and deaths in Virginia will grow as climate change fuels more intense and frequent heat waves.¹⁰ For example, from 1975 to 2010, the Virginia Beach metropolitan area experienced an average of approximately 20 excess deaths per year on dangerously hot summer days.¹¹ ("Excess deaths" are the number of deaths above the daily standardized summertime average for a given area.) Without action to dramatically cut global carbon emissions from current levels, this could increase to an annual average of 170 excess deaths on dangerously hot days by the 2040s.

FIGURE I. AVERAGE NUMBER OF EXTREME SUMMER HEAT DAYS PER YEAR IN VIRGINIA, BY COUNTY, 2007 TO 2016

“Extreme heat days” are defined as June, July, and August days from 2007 to 2016 on which the maximum temperature at a given weather station exceeded the local 90th-percentile value for that station. We used June, July, and August days from 1961 to 1990 to calculate the 90th percentile for each station.



Source: NRDC.¹²

Anyone can get sick from extreme heat, but outdoor workers, young children, older adults, people with chronic diseases like diabetes, and people experiencing poverty are particularly vulnerable.¹³ This is especially pronounced in cities, where climate warming driven by carbon pollution is amplified by tall buildings that block airflow and by heat-absorbing surfaces like asphalt.¹⁴ In Richmond, for instance, daily summer temperatures from 2004 to 2013 were 3.1°F higher, on average, than in nearby rural areas.¹⁵

Heat-related illnesses impact low-income households, many of which are concentrated in city neighborhoods that have a high density of buildings and parking lots and are devoid of shade and vegetation.¹⁶ These households may lack access to official cooling centers or be unable to afford life-saving air-conditioning.¹⁷ More than 22 percent of the children in Virginia’s 20 most urban counties experience poverty, compared with 15 percent in the state overall.¹⁸

COASTAL FLOODS ARE GETTING WORSE—AND COULD DISRUPT EMERGENCY HEALTH SERVICES

Coastal Virginia is experiencing one of the more challenging symptoms of a warming climate: sea level rise. The Sewells Point tide gauge in Norfolk has experienced the equivalent of 18.2 inches of relative sea level rise in the past 100 years, compared with the global average of 7 to 8 inches since 1890.¹⁹ Because of global sea level rise and local land sinking, the low-lying Hampton Roads region in the southeast part of the state is experiencing an increase in

minor tidal floods (also called “nuisance” or “sunny day” floods) that can block roads and damage homes.²⁰ Norfolk had 11 minor flood days in 2016, compared with 4 minor flood days in 1995.²¹ In 2015, nearly half of Portsmouth residents reported they were unable to get in and out of their neighborhoods on at least one occasion that year because of repeated sunny day flooding.²² And more than 60 percent of Hampton Roads residents worry that the effects of sea level rise already put their health at risk.²³

The combination of sea level rise and coastal storms can make evacuation dangerous or impossible and disrupt emergency health services like ambulances, potentially delaying care and leading to loss of life.²⁴ Southern Virginia Beach has a dearth of potential evacuation routes, and



© Yakov Wilson/NOAA Weather in Focus Photo Contest 2015

hospitals and emergency shelters are already difficult to access.²⁵ By 2080, 4 feet of relative sea level rise could flood about 10 percent of the interstate highways and arterial and primary roads in Virginia Beach and Norfolk during exceptionally high tides known as “king tides.”²⁶ If a 100-year storm surge (floods with a 1 percent chance of occurring in a given year) coincided with a king tide, flooding could cover more than 50 percent of roadways in the same area. Note that more than one 100-year flood can occur in a given century.²⁷

Flood-related damage or blocked roadways aren’t good for anyone but can be especially difficult for those with low incomes, who may have trouble paying for rent, food, or doctors’ bills if they can’t get to work.²⁸ Parts of Norfolk and Portsmouth have some of the highest poverty rates in the state.²⁹ Furthermore, 52 percent of area renters spend more than 30 percent of their household income on rent—a marker of housing instability.³⁰

CLIMATE CHANGE COULD CONTAMINATE VIRGINIA'S DRINKING WATER

Sea level rise will affect something many of us take for granted: safe drinking water. More than 5.5 million people lived in Virginia’s coastal watershed counties in 2010, and the coastal population is expected to grow.³¹ Coastal Virginians get their drinking water from a combination of surface water sources and groundwater sources that are largely below sea level.³²

The combination of sea level rise and well pumping (which can allow saltwater under aquifers to flow upward) threatens to make coastal groundwater saltier. Excess salt concentrations in drinking water may increase blood pressure in sensitive individuals and can contribute to strokes and heart attacks.³³ Salt can also corrode water distribution pipes, which increases the likelihood of unhealthy lead or copper contamination.³⁴

Increases in extreme precipitation will likely lead to more contaminated runoff in water and more failures of drinking water systems and wastewater treatment facilities across the country.³⁵ Nearly 70 percent of waterborne disease outbreaks in the United States between 1948 and 1994 were preceded by heavy precipitation.³⁶ In the Southeast, the amount of rain falling in the heaviest one-day storms increased 27 percent from 1958 to 2016.³⁷ In Virginia, the number of days with more than 2 inches of precipitation increased from 1995 to 2014, and that trend is expected to continue as the climate warms.³⁸ This poses a problem for cities, like Richmond, that have combined sewer overflow systems.³⁹ During heavy rains, these combined systems dump untreated sewage and other contaminants into rivers, lakes, and coastal waters. Combined sewer overflows were a major source of *Escherichia coli*—an indicator of fecal contamination—in Richmond’s James River Basin in 2012.⁴⁰



© Will Parson/Chesapeake Bay Program

RISING TEMPERATURES COULD MAKE VIRGINIA'S SEAFOOD DANGEROUS TO EAT

Virginia is home to a multitude of fishable streams and lakes and more than 3,300 miles of marine coastline.⁴¹ But rising temperatures threaten the safety of the fish and shellfish those waters provide—including oysters, the pride of coastal Virginia.⁴²

Vibriosis, which is spread by bacteria-laden seawater or seafood, can cause symptoms ranging from nausea to skin infections.⁴³ The illness affects an estimated 80,000 people and causes about 100 deaths in the United States every year. Anyone can get vibriosis, but severe complications are more likely for people with weakened immune systems or chronic diseases like cancer or liver disease, or for those who take medications to reduce stomach acid.⁴⁴

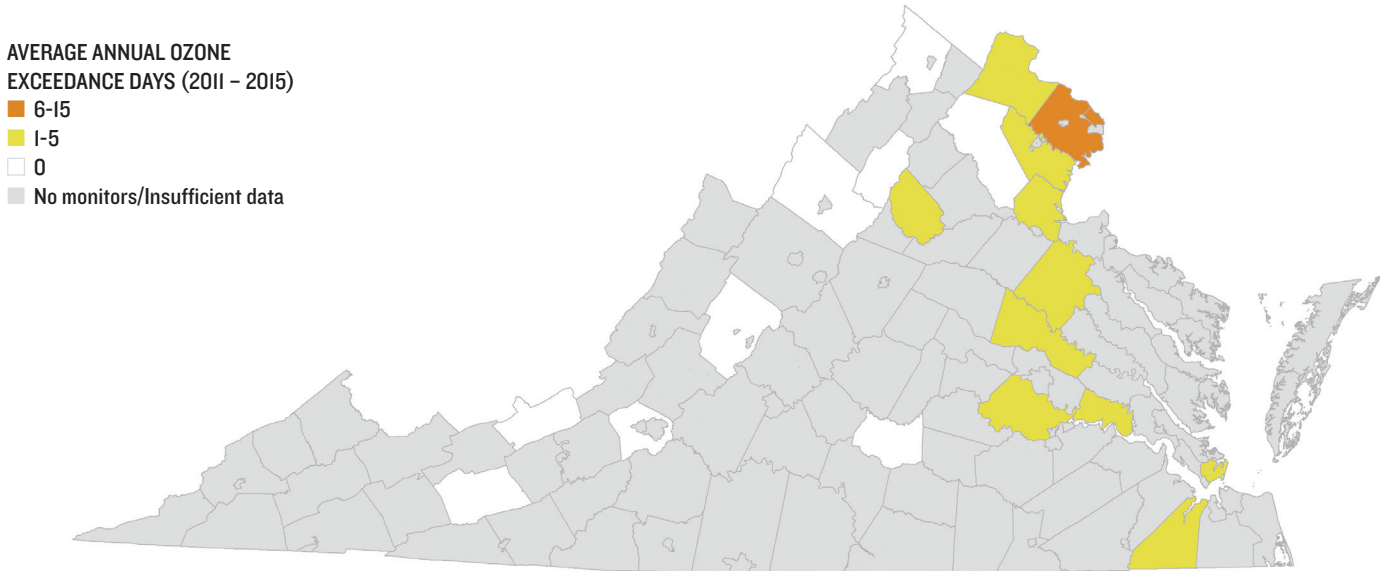
Vibrio bacteria concentrations in the temperate North Atlantic have risen over the last half century, and researchers have linked this rise to warming sea surface temperatures.⁴⁵ As the Chesapeake Bay area gets warmer, the likelihood of *Vibrio vulnificus* bacteria, which can cause symptoms like bloody diarrhea and vomiting, is expected to increase in bay water.⁴⁶ Warmer temperatures could also increase the concentration of *V. parahaemolyticus* bacteria, which can cause deadly bloodstream infections, in the area’s oysters.

CLIMATE CHANGE PUTS VIRGINIA'S PROGRESS TOWARD CLEANER SKIES AT RISK

Virginia’s air quality has improved since 2004 largely because of federal pollution limits.⁴⁷ However, climate change could undermine the state’s progress toward cleaner air and make it harder to meet future air quality standards.⁴⁸ This is especially pertinent in the 12 Virginia counties that already experience an average of 2 to 9.7 unhealthy smog days per year (Figure 2).⁴⁹ Smog forms when pollution from power plants, vehicles, and other sources reacts with sunlight to create ground-level ozone.⁵⁰ Rising temperatures can speed up this process and lead to more smog. In the southeastern United States, warmer and drier fall weather could also extend the summer smog season into fall.⁵¹

FIGURE 2. VIRGINIA COUNTIES AVERAGING ONE OR MORE UNHEALTHY GROUND-LEVEL OZONE DAYS PER YEAR, 2011 TO 2015

Ozone exceedances are days when an eight-hour average concentration of ozone exceeds the EPA’s 2015 Ozone National Ambient Air Quality Standard of 0.070 parts per million.



Source: NRDC.⁵⁵

Smog and small particulate matter, another type of pollution from burning fossil fuels, are powerful triggers for asthma, threatening the health of Virginia’s estimated 159,000 children and 518,000 adults with the condition.⁵² These forms of air pollution have also been linked to preterm births, birth defects, developmental delays in children, strokes, heart attacks, dementia in older adults, lung cancer, and other health problems.⁵³ Smog and particle pollution from Virginia power plants cause an estimated 400 premature deaths per year from asthma and other causes in Virginia and nearby states.⁵⁴

Climate-fueled increases in smog will increase health care costs for asthma, which is already an expensive disease to treat.⁵⁶ In 2012, for example, asthma generated an estimated \$2,208 in medical costs per patient in Virginia and a cumulative cost of \$76.7 million in lost work and school days.⁵⁷ The burden of worsening air quality will fall heavily on low-income families and children of color. For example, in the Washington-Arlington-Alexandria metropolitan area, there are nearly twice as many African-American and Hispanic households in severely or moderately inadequate housing as there are white households.⁵⁸ Children who live in poor-quality housing are 45 percent more likely to be diagnosed with asthma and 59 percent more likely to be treated in an emergency room for it.⁵⁹

ALLERGY SEASONS ARE GETTING LONGER AND MORE SEVERE

Seasonal pollen allergies, also known as hay fever, are common across Virginia. In 2016, Richmond was the 14th most challenging city in the nation in terms of spring allergies.⁶⁰ Hay fever symptoms, such as congestion and headache, can range from mildly annoying to downright disruptive, affecting sleep, mood, and quality of life.⁶¹

Rising temperatures are leading to earlier spring allergy seasons across the United States.⁶² The carbon dioxide driving climate change is also stimulating plant growth, boosting pollen production. From 2001 to 2010, the oak pollen season started nearly four days earlier, on average, than in the previous decade, according to a study of six monitoring sites in the southeastern United States.⁶³ Peak pollen counts averaged 117 percent higher in that same period. In 2017, Allergy Partners of Richmond reported its fourth-highest tree pollen count since the group began recording data outside its clinic in 1989.⁶⁴

Asthma threats increase when there’s more pollen in the air. In 2010, asthma triggered by oak pollen led to an estimated 8,800 emergency room visits in the Southeast. By the 2050s, emergency room visits for oak-related asthma attacks could increase 4 percent under continued high levels of carbon pollution.⁶⁵



Blacklegged ticks, which can carry the bacteria that cause Lyme disease, are expanding to new counties in Virginia at an explosive rate. In 1996, the ticks were reported or established in only 12 of Virginia’s 95 counties; this had increased to 72 counties by 2016.

MOSQUITO- AND TICK-BORNE INFECTIONS ARE INCREASING

Climate change helps make it possible for ticks and mosquitoes to live in new places and be active earlier in the year.⁶⁶ That’s bad news for the more than 49,260 Virginians who work in outdoor occupations such as farming, landscaping, and highway construction.⁶⁷ It also affects millions of Virginia residents who enjoy visiting natural areas, gardening, and other outdoor recreation every year.⁶⁸

Virginia is one of 14 hot-spot states for Lyme disease, the most common tick-borne illness in the United States.⁶⁹ In its early stages, Lyme disease causes flulike symptoms. Later on—weeks or months after a bite by an infected tick—people with Lyme disease can suffer debilitating muscle and joint pain, headaches, memory problems, and even fatal heart damage.⁷⁰ In Virginia, there were 10,761 confirmed or probable cases of Lyme disease reported between 2008 and 2015.⁷¹

Blacklegged ticks, which can carry the bacteria that cause Lyme disease, are expanding to new counties in Virginia at an explosive rate. In 1996, the ticks were reported or established in only 12 of Virginia’s 95 counties; this had increased to 72 counties by 2016 (Figure 3).⁷² Lyme

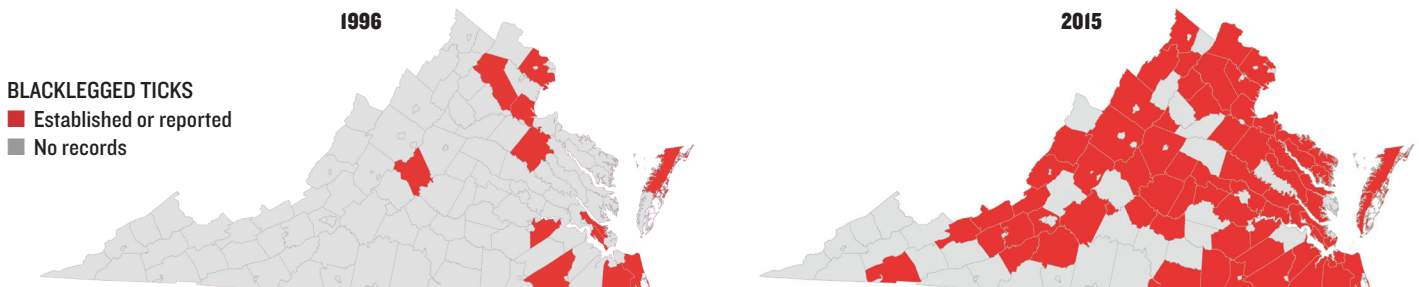
disease cases are also spreading to new areas of the state, potentially due to a combination of climate change, habitat change, and local increases in the population of deer and mice that carry ticks.⁷³ In addition, warmer springs will likely encourage an earlier start to Lyme disease season. By the 2060s, the season could begin three weeks earlier in Virginia than it did from 1992 to 2007.⁷⁴

West Nile virus was first reported in Virginia in 2002, and a total of 163 cases have been reported in the state since then.⁷⁵ The disease, which is typically spread by mosquitoes, causes symptoms like vomiting and fatigue in about 1 in 5 people who are infected.⁷⁶ More rarely, infected patients develop severe neurological illnesses that can be fatal. From 2036 to 2049, extremely hot and dry years could approximately triple the annual number of neuroinvasive West Nile cases in Virginia.⁷⁷

Rising temperatures and humidity are also extending the mosquito season in Virginia cities, increasing the possibility of transmission of Zika, dengue, and other viruses.⁷⁸ In the state’s largest cities, there was an average of 131 suitable days each year for Asian tiger mosquito activity from 2006 to 2015, compared with 113 such days annually from 1980 to 1989.⁷⁹

FIGURE 3. DISTRIBUTION OF BLACKLEGGED TICKS IN VIRGINIA, 1996 AND 2015

Counties in Virginia where blacklegged ticks were reported (fewer than six ticks of a single life stage) or established (six or more ticks or two tick life stages) in 1996 and 2015.



Source: Modified from Eisen et al., *Journal of Medical Entomology* 53 (2016).

ACTING ON CLIMATE CAN PROTECT OUR HEALTH

The good news is that cleaning up power plants, vehicles, and other big sources of pollution will help protect our health by limiting the dangerous effects of climate change and by cutting unhealthy smog, particulate matter, and other air pollution.

Virginia has already made progress to address climate change, reducing total carbon dioxide emissions by more than 20 percent from 2005 to 2015.⁸⁰ Those efforts have also helped clean up the air Virginians breathe. For example, Arlington County's efforts to make traffic flow more efficiently and to enhance public transportation, cycling, and walking avoided the emission of more than 511,000 tons of carbon dioxide (equivalent to the emissions from more than 1.1 billion passenger vehicle miles) from 2008 to 2014. These efforts also eliminated more than 950,000 pounds of nitrogen oxides, a building block of smog and particle pollution, in the same period.⁸¹ And from 2007 to 2017, Virginia's wind and solar power plants averted the emission of more than 1.6 million metric tons of carbon dioxide, more than 4,000 metric tons of sulfur dioxide, and more than 2,000 metric tons of nitrogen oxides.⁸²

In March 2018, the Virginia state legislature passed a bill that mandates the investment of more than \$1 billion in energy efficiency (including programs targeting low-income households), solar and wind energy, and electric grid modernization.⁸³ But there's a lot more to do. For instance, the state took a big step forward in November 2017 by approving a proposal to cut carbon pollution by 30 percent between 2020 and 2030.⁸⁴ As part of that plan, Virginia intends to join the Regional Greenhouse Gas Initiative (RGGI), a multistate program to limit carbon pollution from power plants. The air pollution reduced through the program from 2009 to 2014 generated an estimated \$5.7 billion in health benefits in RGGI states and neighboring states—including Virginia.⁸⁵ Over that period, RGGI helped

Virginia residents avoid a total of up to 53 premature adult deaths, an estimated 761 asthma attacks, and about 3,621 missed work days.⁸⁶ If Virginia joins RGGI, it will further boost air quality benefits to RGGI states and to their neighbors.

The health benefits of cutting carbon pollution aren't limited to reducing climate-related threats and improving air quality. Transportation is Virginia's largest source of carbon dioxide pollution.⁸⁷ A smarter and cleaner transportation system (for example, one that incentivizes more efficient vehicles and alternatives to cars) could help limit emissions and reduce the stress associated with traffic jams, improve access to health care among those who can't drive or don't own a car, and reduce premature mortality thanks to increased physical activity.⁸⁸

Virginia also needs to create and implement more detailed plans to address the health impacts of climate change that are already being felt today. The state's 2008 climate action plan recommended several health initiatives—including tracking temperature-driven increases in the incidence of allergic diseases—but there has been little progress since then.⁸⁹ As of March 2018, the Virginia Department of Health website did not even mention climate change. In the near term, the Department of Health should develop a climate vulnerability assessment that combines data on socioeconomic and other health-risk factors with information about the ability of communities, health providers, and other key institutions to cope with the health consequences of climate threats. Such an assessment would help the state make evidence-based choices about which climate impacts to prioritize and how best to help the people most vulnerable to those impacts.⁹⁰

The bottom line is that Virginia residents have much to gain from climate action—and lives to lose if we fail to clean up climate-changing pollution and build resilience to the shifts that have already occurred.

ENDNOTES

- 1 Donald J. Wuebbles et al., eds. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, U.S. Global Change Research Program (hereinafter USGCRP), 2017, science2017.globalchange.gov/downloads/. Gary M. Lackmann, “Hurricane Sandy Before 1900 and After 2100,” *Bulletin of the American Meteorological Society* (April 2015): 547-560, journals.ametsoc.org/doi/10.1175/BAMS-D-14-00123.1.
- 2 Allison Crimmins et al., eds., *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, USGCRP, 2016, https://s3.amazonaws.com/climatehealth2016/low/ClimateHealth2016_FullReport_small.pdf.
- 3 Vignesh Gowrishankar and Amanda Levin, *America’s Clean Energy Frontier: The Pathway to a Safer Climate Future*, Natural Resources Defense Council (hereinafter NRDC), 2017, www.nrdc.org/resources/americas-clean-energy-frontier-pathway-safer-climate-future. Alfredo Morabia and Georges C. Benjamin, “Preparing and Rebuilding After Natural Disasters: A New Public Health Normal” *American Journal of Public Health* 108, no. 1 (January 2018): 9-10, ajphaphublications.org/doi/abs/10.2105/AJPH.2017.304202.
- 4 NOAA National Climatic Data Center, “State Annual and Seasonal Time Series,” 2018, www.ncdc.noaa.gov/temp-and-precip/state-temps/ (accessed March 9, 2018).
- 5 G. Brooke Anderson and Michelle L. Bell, “Heat Waves in the United States: Mortality Risk During Heat Waves and Effect Modification by Heat Wave Characteristics in 43 U.S. Communities,” *Environmental Research Letters* 119, no. 2 (February 2011): 210-218, doi:10.1289/ehp.1002313.
- 6 NRDC analysis of data from NOAA National Climatic Data Center, “Climate Data Online,” n.d., www.ncdc.noaa.gov/cdo-web/search (accessed March 12, 2018).
- 7 An estimated 3,009,320 of Virginia’s 8,256,630 residents lived in extreme-heat counties in 2015. NRDC, “Climate Change and Health: Extreme Heat—State by State,” n.d., www.nrdc.org/sites/default/files/extreme_heat_chart.pdf (accessed March 26, 2018).
- 8 Marcus C. Sarofim et al., “Temperature-Related Death and Illness,” chapter 2 in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, USGCRP, 2016, https://s3.amazonaws.com/climatehealth2016/low/ClimateHealth2016_02_Temperature_small.pdf.
- 9 Virginia Department of Health, “Weather-Related Surveillance,” n.d., www.vdh.virginia.gov/surveillance-and-investigation/syndromic-surveillance/weather-surveillance/ (accessed February 26, 2018).
- 10 Sarofim et al., “Temperature-Related Death and Illness.”
- 11 Juanita Constible, “Killer Summer Heat: Paris Agreement Compliance Could Avert Hundreds of Thousands of Needless Deaths in America’s Cities,” NRDC, June 2017, www.nrdc.org/resources/killer-summer-heat-paris-agreement-compliance-could-avert-hundreds-thousands-needless.
- 12 NRDC, “Climate Change and Health: Extreme Heat,” www.nrdc.org/climate-change-and-health-extreme-heat/#/map (accessed December 20, 2017).
- 13 Sarofim et al., “Temperature-Related Death and Illness.”
- 14 U.S. Environmental Protection Agency, *Reducing Urban Heat Islands: Compendium of Strategies: Draft*, 2008, www.epa.gov/heat-islands/heat-island-compendium.
- 15 Alyson Kenward et al., *Summer in the City: Hot and Getting Hotter*, Climate Central, 2014, assets.climatecentral.org/pdfs/UrbanHeatIsland.pdf.
- 16 Bill M. Jesdale et al., “The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation,” *Environmental Health Perspectives* 121, no. 7 (July 2013): 811-817, ehp.niehs.nih.gov/1205919/.
- 17 Ruth Ann Norton et al., *Achieving Health and Social Equity Through Housing: Understanding the Impact of Non Energy Benefits in the United States*, Green & Healthy Homes Initiative, 2017, www.greenandhealthyhomes.org/sites/default/files/AchievingHealth%26SocialEquity_final-lo.pdf. Andrew M. Fraser, “Household Accessibility to Heat Refuges: Residential Air Conditioning, Public Cooled Space, and Walkability,” *Environment and Planning B: Urban Analytics and City Science* 44, no. 6 (2017): 1036-1055, journals.sagepub.com/doi/pdf/10.1177/0265813516657342.
- 18 NRDC analysis of U.S. Census and County Health Ranking data. U.S. Census Bureau, “2010 Census Urban and Rural Classification,” n.d., www.census.gov/geo/reference/urban-rural.html (accessed December 20, 2017). County Health Rankings, “Virginia, 2017,” www.countyhealthrankings.org/ (accessed December 20, 2017).
- 19 NOAA Tides & Currents, “Relative Sea Level Trend, 8638610 Sewells Point, Virginia,” n.d., https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8638610 (revised October 15, 2013). W.V. Sweet et al., “Sea Level Rise,” chapter 12 in *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, USGCRP, 2017, science2017.globalchange.gov/downloads/.
- 20 Jennifer Runkle et al., “State Climate Summaries: Virginia,” NOAA National Centers for Environmental Information, 2017, statesummaries.ncics.org/va.
- 21 William V. Sweet et al., “2016 State of U.S. High Tide Flooding and a 2017 Outlook,” NOAA Center for Operational Oceanographic Products and NOAA National Centers for Environmental Information, June 2017, www.ncdc.noaa.gov/sotc/national/2017/05/supplemental/page-1.
- 22 Joshua G. Behr, Rafael Diaz, and Molly Mitchell, “Building Resiliency in Response to Sea Level Rise and Recurrent Flooding: Comprehensive Planning in Hampton Roads,” *Virginia News Letter* 92, no. 1 (January 2016): 1-6, digitalcommons.odu.edu/cgi/viewcontent.cgi?article=1001&context=vmasc_pubs.
- 23 Juita-Elena Yusuf et al., “Hampton Roads Residents’ Perceptions of Sea Level Rise and Flooding Adaptation,” Old Dominion Resilience Collaborative, Occasional Paper Series, 2017, digitalcommons.odu.edu/odurc_ops/1.
- 24 Jesse E. Bell et al., “Impacts of Extreme Events on Human Health,” chapter 4 in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, USGCRP, 2016, health2016.globalchange.gov/downloads. Maria Luskova et al., *Methodology for Measuring Social Vulnerability Due to Failure of Critical Land Transport Infrastructure Elements*, Rain Project, 2017, http://rain-project.eu/wp-content/uploads/2017/08/3.4_final.pdf.
- 25 Hua Liu, Joshua G. Behr, and Rafael Diaz, “Population Vulnerability to Storm Surge Flooding in Coastal Virginia, USA,” *Integrated Environmental Assessment and Management* 12, no. 3 (2016): 500-509, <https://setac.onlinelibrary.wiley.com/doi/abs/10.1002/ieam.1705>.
- 26 Jeffrey M. Sadler et al. “Impact of Sea-Level Rise on Roadway Flooding in the Hampton Roads Region, Virginia,” *Journal of Infrastructure Systems* 23, no. 4 (December 2017), [ascelibrary.org/doi/full/10.1061/\(ASCE\)IS.1943-555X.0000397](https://ascelibrary.org/doi/full/10.1061/(ASCE)IS.1943-555X.0000397).
- 27 Margaret A. Grounds et al., “Expressing Flood Likelihood: Return Period Versus Probability,” *Weather, Climate, and Society* 10 (January 2018): 5-7, journals.ametsoc.org/doi/abs/10.1175/WCAS-D-16-0107.1.
- 28 Hua Liu, Joshua G. Behr, and Rafael Diaz, “Population Vulnerability.”
- 29 Peter Galuszka, “Where Virginia’s Poor Live,” *Washington Post*, January 6, 2014, www.washingtonpost.com/blogs/all-opinions-are-local/wp/2014/01/06/where-virginias-poor-live/?utm_term=.5bdbbed3e03c.
- 30 U.S. Census Bureau, “Community Facts: Selected Housing Characteristics, 2012–2016,” American Community Survey 5-Year Estimates, 2018, factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF (accessed February 26, 2018).
- 31 Kristen Crossett, *National Coastal Population Report: Population Trends from 1970 to 2020*, NOAA and U.S. Census Bureau, 2003, aamboceanservice.blob.core.windows.net/oceanservice-prod/facts/coastal-population-report.pdf.

- 32 Virginia Department of Environmental Quality, *Status of Virginia's Water Resources: A Report on Virginia's Water Resources Management Activities*, October 2012, www.deq.virginia.gov/Portals/0/DEQ/LawsAndRegulations/GeneralAssemblyReports/Water_Resources_Report.pdf. Hampton Roads Planning District Commission, *Chloride Concentrations in Hampton Roads Drinking Water Sources*, 2014, www.hrpdeva.gov/uploads/docs/FINAL_ChloridesHRDrinkingWaterSources_Sept.2014.pdf.
- 33 Paolo Vineis et al., "Climate Change Impacts on Water Salinity and Health," *Journal of Epidemiology and Global Health* 1 (December 2011): 5-10, www.sciencedirect.com/science/article/pii/S2210600611000086. Brian Benham et al., "Virginia Household Water Quality Program: Sodium and Chloride in Household Drinking Water," Virginia Cooperative Extension, Publication 442-661, 2011, pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/442/442-661/442-661_pdf.pdf.
- 34 E.G. Stets et al., "Increasing Chloride in Rivers of the Conterminous U.S. and Linkages to Potential Corrosivity and Lead Action Level Exceedances in Drinking Water," *Science of the Total Environment* 613-614 (2018): 1498-1509, www.sciencedirect.com/science/article/pii/S0048969717318223?via%3Dihub.
- 35 Juli Trtanj et al., "Climate Impacts on Water-Related Illnesses," chapter 6 in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, USGCRP, 2016, health2016.globalchange.gov/downloads.
- 36 Ibid.
- 37 D.R. Easterling et al., "Precipitation Change in the United States," chapter 7 in *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, USGCRP, 2017, science2017.globalchange.gov/downloads/.
- 38 Jennifer Runkle et al., "State Climate Summaries: Virginia."
- 39 Richmond Department of Public Utilities, "Combined Sewer Overflow (CSO) Project," n.d., www.richmondgov.com/publicutilities/projectCombinedSewerOverflow.aspx (accessed March 9, 2018).
- 40 Virginia Department Environmental Quality, Virginia Department of Conservation and Recreation, and Virginia Department of Health, *Virginia Water Quality Assessment 305(b)/303(d) Integrated Report 2016*, August 2017, www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityAssessments/IntegratedReport/2016/ir16_Integrated_Report_Full_Draft.pdf.
- 41 Virginia Department of Game and Inland Fisheries, "Virginia Fishes," n.d., www.dgif.virginia.gov/wildlife/fish/ (accessed March 9, 2018). NOAA Office for Coastal Management, "Shoreline Mileage of the United States," n.d., coast.noaa.gov/data/docs/states/shorelines.pdf (accessed January 18, 2018).
- 42 Juli Trtanj et al., "Climate Impacts." Lewis Ziska et al., "Food Safety, Nutrition, and Distribution," chapter 7 in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, USGCRP, 2016, health2016.globalchange.gov/downloads.
- 43 Centers for Disease Control and Prevention (hereinafter CDC), "Vibrio Species Causing Vibriosis," n.d., www.cdc.gov/vibrio/index.html (updated October 27, 2017).
- 44 CDC, "Vibrio Species Causing Vibriosis: People at Risk," n.d., www.cdc.gov/vibrio/people-at-risk.html (updated January 17, 2017).
- 45 Luigi Vezzulli et al., "Climate Influence on Vibrio and Associated Diseases During the Past Half-Century in the Coastal North Atlantic," *Proceedings of the National Academies of Sciences* 113, no. 34 (August 2016): E5062-E5071, doi.org/10.1073/pnas.1609157113.
- 46 Barbara A. Muhling, "Projections of the Future Occurrence, Distribution, and Seasonality of Three Vibrio Species in the Chesapeake Bay Under a High-Emission Climate Change Scenario," *GeoHealth* 1 (2017): [doi:10.1002/2017GH000089](https://doi.org/10.1002/2017GH000089).
- 47 Chuck Turner and Namita Verma, *Five-Year Air Quality Monitoring Network Assessment*, Virginia Department of Environmental Quality, 2015, www3.epa.gov/ttn/amtic/5yrnetassess.html. Commonwealth of Virginia, "Virginia Performs: Air Quality," vaperforms.virginia.gov/indicators/naturalResources/airQuality.php (updated September 26, 2016).
- 48 Neal Fann et al., "Air Quality Impacts," chapter 3 in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, USGCRP, 2016, health2016.globalchange.gov/downloads.
- 49 Unpublished NRDC analysis done as part of NRDC, "Climate Change and Health: Air Quality," www.nrdc.org/climate-change-runkland-health-air-quality#/map (accessed December 20, 2017).
- 50 Neal Fann et al., "Air Quality Impacts."
- 51 Yuzhong Zhang and Yuhang Wang, "Climate-Driven Ground-Level Ozone Extreme in the Fall Over the Southeast United States," *Proceedings of the National Academy of Sciences* 113, no. 36 (2016), www.pnas.org/content/113/36/10025.abstract.
- 52 The *estimated* prevalence is derived from national and/or state data and adjusted for the age-specific population of each area. Many other factors may affect *actual* prevalence. American Lung Association, "Estimated Prevalence and Incidence of Lung Disease," 2016, <http://www.lung.org/our-initiatives/research/monitoring-trends-in-lung-disease/estimated-prevalence-and-incidence-of-lung-disease>, (accessed May 9, 2017).
- 53 Michael Guarneri and John R. Balmes, "Outdoor Air Pollution and Asthma," *The Lancet* 383, no. 9928 (May 2014): 1581-1592, [www.thelancet.com/journals/lancet/article/PIIS0140-6736\(14\)60617-6/fulltext](http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(14)60617-6/fulltext). Frederica P. Perera, "Multiple Threats to Child Health from Fossil Fuel Combustion: Impacts of Air Pollution and Climate Change," *Environmental Health Perspectives* 125 (2017): 141-148, dx.doi.org/10.1289/EHP299. Sheng Ren et al., "Periconception Exposure to Air Pollution and Risk of Congenital Malformations," *Journal of Pediatrics* 193 (February 2018): 76-84.e6, [linkinghub.elsevier.com/retrieve/pii/S0022-3476\(17\)31330-6](https://linkinghub.elsevier.com/retrieve/pii/S0022-3476(17)31330-6). Philip J. Landrigan et al., "The Lancet Commission on Pollution and Health," *The Lancet* (October 2017): [dx.doi.org/10.1016/S0140-6736\(17\)32345-0](https://dx.doi.org/10.1016/S0140-6736(17)32345-0). Lida Gharibvand et al., "The Association Between Ambient Fine Particulate Air Pollution and Lung Cancer Incidence: Results from the AHSMOG-2 Study," *Environmental Health Perspectives* 125, no. 3 (March 2017): 378-284, www.ncbi.nlm.nih.gov/pmc/articles/PMC5332173/pdf/EHP124.pdf.
- 54 Stefani L. Penn et al., "Estimating State-Specific Contributions to PM_{2.5}- and O₃-Related Health Burden from Residential Combustion and Electricity Generating Unit Emissions in the United States," *Environmental Health Perspectives* 125, no. 3 (March 2017): 324-332, ehp.niehs.nih.gov/ehp550/.
- 55 NRDC, "Climate Change and Health: Air Quality,"
- 56 Neal Fann et al., "The Geographic Distribution and Economic Value of Climate Change-Related Ozone Health Impacts in the United States in 2030," *Journal of the Air & Waste Management Association* 65 (2015): 570-580, dx.doi.org/10.1080/10962247.2014.996270.
- 57 Tursynbek Nurmagambetov et al., "State-Level Medical and Absenteeism Cost of Asthma in the United States," *Journal of Asthma* 54, no. 4 (2017): 357-370, <http://dx.doi.org/10.1080/02770903.2016.1218013>.
- 58 U.S. Census Bureau, "2015 American Housing Survey," 2017, www.census.gov/programs-surveys/ahs.html (accessed December 20, 2017).
- 59 Helen K. Hughes et al., "Pediatric Asthma Health Disparities: Race, Hardship, Housing, and Asthma in a National Survey," *Academic Pediatrics* 17 (2017): 127-134, [www.academicpedsjnl.net/article/S1876-2859\(16\)30501-0/abstract](http://www.academicpedsjnl.net/article/S1876-2859(16)30501-0/abstract).
- 60 Asthma and Allergy Foundation of America, "Spring Allergy Capitals 2016," 2016, www.aafa.org/media/Spring-Allergy-Capitals-2016-Rankings.pdf.
- 61 Eli O. Meltzer et al., "Findings from an Online Survey Assessing the Burden and Management of Seasonal Allergic Rhinoconjunctivitis in U.S. Patients," *Journal of Allergy and Clinical Immunology: In Practice* 5 (2017): 779-789, www.sciencedirect.com/science/article/pii/S221321981630544X?via%3Dihub.

- 62 Neal Fann et al., “Air Quality Impacts.”
- 63 Yong Zhang et al., Supporting Information, “Allergenic Pollen Season Variations in the Past Two Decades Under Changing Climate in the United States,” *Global Change Biology* 21, no. 4 (April 2015): 1581-1589, onlinelibrary.wiley.com/doi/10.1111/gcb.12755/abstract.
- 64 John Boyer, “This Year Brought Richmond’s Fourth-Highest Tree Pollen Count in 30 Years,” *Richmond Times-Dispatch*, April 19, 2017, www.richmond.com/weather/this-year-brought-richmond-s-fourth-highest-tree-pollen-count/article_13f19bcc-a583-5c99-93a3-d6b5aeddlabb.html.
- 65 Susan C. Anenberg et al., “Impacts of Oak Pollen on Allergic Asthma in the United States and Potential Influence of Future Climate Change,” *GeoHealth* 1, no. 3 (May 2017): 80-92, onlinelibrary.wiley.com/doi/10.1002/2017GH000055/full.
- 66 Charles B. Beard et al., “Vector-Borne Diseases,” chapter 5 in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, USGCRP, 2016, health2016.globalchange.gov/downloads.
- 67 Conservative NRDC estimate based on Bureau of Labor Statistics, “May 2016 State Occupational Employment and Wage Estimates,” n.d., www.bls.gov/oes/current/oesrcst.htm (updated March 31, 2017).
- 68 Virginia Department of Conservation and Recreation, “Outdoor Recreation Participation Rates,” 2017, www.dcr.virginia.gov/recreational-planning/vop-participation-activities (accessed January 20, 2018).
- 69 Amy M. Schwartz et al., “Surveillance for Lyme Disease—United States, 2008–2015,” *Morbidity and Mortality Weekly Report* 66, no. 22 (November 2017): 1-12, www.cdc.gov/mmwr/volumes/66/ss/ss6622a1.htm.
- 70 CDC, “Signs and Symptoms of Untreated Lyme Disease,” n.d., www.cdc.gov/lyme/signs_symptoms/index.html (updated October 26, 2016).
- 71 CDC, “County-Level Lyme Disease Data from 2000–2016,” n.d., www.cdc.gov/lyme/stats/index.html (accessed March 9, 2018).
- 72 Rebecca J. Eisen et al., “County-Scale Distribution of *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae) in the Continental United States,” *Journal of Medical Entomology* 53, no. 2 (2016): 349-386, academic.oup.com/jme/article/53/2/349/2459744.
- 73 Jie Li et al., “Spatial and Temporal Emergence Pattern of Lyme Disease in Virginia,” *American Journal of Tropical Medicine and Hygiene* 91, no. 6 (2014): 1166-1172, www.ncbi.nlm.nih.gov/pubmed/25331806. A. Marm Kilpatrick et al., “Lyme Disease Ecology in a Changing World: Consensus, Uncertainty and Critical Gaps for Improving Control,” *Philosophical Transactions of the Royal Society B* 372 (2017): 20160117, [dx.doi.org/10.1098/rstb.2016.0117](https://doi.org/10.1098/rstb.2016.0117).
- 74 Andrew J. Monaghan et al., “Climate Change Influences on the Annual Onset of Lyme Disease in the United States,” *Ticks and Tick-borne Diseases* 6 (2016): 615-622, [linkinghub.elsevier.com/retrieve/pii/S1877-959X\(15\)00087-4](https://linkinghub.elsevier.com/retrieve/pii/S1877-959X(15)00087-4).
- 75 CDC, “West Nile Virus: Final Cumulative Maps & Data for 1999–2016,” n.d., www.cdc.gov/westnile/statsmaps/cumMapsData.html (updated July 15, 2016).
- 76 CDC, “West Nile Virus: Transmission,” n.d., www.cdc.gov/westnile/transmission/index.html (updated October 20, 2017). CDC, “West Nile Virus: Symptoms, Diagnosis, & Treatment,” n.d., www.cdc.gov/westnile/symptoms/index.html (updated August 2, 2017).
- 77 Sara H. Paull et al., “Drought and Immunity Determine the Intensity of West Nile Virus Epidemics and Climate Change Impacts,” *Philosophical Transactions of the Royal Society B* 284 (February 2017): 20162078, [dx.doi.org/10.1098/rspb.2016.2078](https://doi.org/10.1098/rspb.2016.2078). Sara H. Paull et al., “Drought and Immunity,” Supplementary Information Figures.
- 78 CDC, “Zika Virus: Potential Range in U.S.,” n.d., www.cdc.gov/zika/vector/range.html (updated February 23, 2018). Andrew J. Monaghan et al., “On the Seasonal Occurrence and Abundance of the Zika Virus Vector Mosquito *Aedes aegypti* in the Contiguous United States,” *PLOS Current Outbreaks* (March 2016), Edition 1, [doi:10.1371/currents.outbreaks.50dfc7f46798675fc63e7d7da563da76](https://doi.org/10.1371/currents.outbreaks.50dfc7f46798675fc63e7d7da563da76).
- 79 Alyson Kenward and Jennifer Brady, “More Mosquito Days Increasing Zika Risk in U.S.,” Climate Central, July 27, 2016, <http://www.climatecentral.org/news/more-mosquito-days-increasing-zika-risk-in-us-20553>.
- 80 U.S. Energy Information Administration (hereinafter EIA), “State Carbon Dioxide Emissions Data, Table 1: State Emissions by Year, 1990–2015,” October 24, 2017, www.eia.gov/environment/emissions/state/.
- 81 Arlington County, “Greenhouse Gas Emissions Reduced by ACCS,” n.d., transportation.arlingtonva.us/key-performance-measures/environment-energy-health-economy/emissions/ (accessed December 20, 2017). EPA, “Greenhouse Gas Equivalencies Calculator,” n.d., www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (updated September 2017).
- 82 Dev Millstein et al., “The Climate and Air-Quality Benefits of Wind and Solar Power in the United States: Supplementary Tables,” *Nature Energy* 2 (2017), Article 17134, www.nature.com/articles/nenergy2017134?WT.feed_name=subjects_energy-and-society. EPA, “Greenhouse Gas Equivalencies Calculator.”
- 83 Walton Shepherd, “A Fresh Start for Clean Energy in Virginia,” NRDC, March 2, 2018, www.nrdc.org/experts/walton-shepherd/fresh-start-clean-energy-virginia.
- 84 Walton Shepherd, “McAuliffe’s Climate Leadership Hits Historic Milestone,” NRDC, November 22, 2017, www.nrdc.org/experts/walton-shepherd/mcauliffes-climate-leadership-hits-historic-milestone. Office of the Governor, “Governor McAuliffe Statement on Virginia Air Board Approval of Clean Energy Virginia Initiative,” November 16, 2017, <https://governor.virginia.gov/newsroom/newsarticle?articleId=21768>.
- 85 Michelle Manion et al., *Analysis of the Public Health Impacts of the Regional Greenhouse Gas Initiative, 2009–2014*, Abt Associates, 2017, abtassociates.com/RGGI.
- 86 Michelle Manion et al., “State Level Results,” appendix E in *Analysis of the Public Health Impacts of the Regional Greenhouse Gas Initiative*.
- 87 EIA, “State Carbon Dioxide Emissions Data, Table 3: 2015 State Emissions by Sector,” October 24, 2017, www.eia.gov/environment/emissions/state/.
- 88 Bob Pishue, “Prioritizing Spending Key to Unlocking Mobility Benefits,” INRIX, September 27, 2017, inrix.com/blog/2017/09/us-hotspots/. Christopher E. Ferrell, *The Benefits of Transit in the United States: A Review and Analysis of Benefit-Cost Studies*, Mineta Transportation Institute, 2015, transweb.sjsu.edu/PDFs/research/1425-US-transit-benefit-cost-analysis-study.pdf. Jinghong Gao et al., “Public Health Co-benefits of Greenhouse Gas Emissions Reductions: A Systematic Review,” *Science of the Total Environment* 627 (June 2018): 388-402, www.sciencedirect.com/science/article/pii/S0048969718302341?via%3Dihub.
- 89 Office of the Secretary of Natural Resources, *Virginia Accomplishments Since the 2008 Climate Action Plan Release*, December 2014, naturalresources.virginia.gov/media/5081/vims-climate-audit.pdf. Georgetown Climate Center, “Preparing for Climate Change in Virginia,” n.d., www.georgetownclimate.org/adaptation/state-information/virginia/overview.html (accessed March 9, 2018).
- 90 Arie Ponce Manangan et al., *Assessing Health Vulnerability to Climate Change: A Guide for Health Departments*, CDC, n.d., www.cdc.gov/climateandhealth/pubs/AssessingHealthVulnerabilitytoClimateChange.pdf (accessed March 21, 2018).