A number of coastal communities in the Northeast region have strong social and cultural ties to marine fisheries, and in some communities, fisheries represent an important economic activity as well.[196,197] Future ocean warming and acidification, which are expected under all scenarios considered, would affect fish stocks and fishing opportunities available to coastal communities. Fisheries targeting species at the southern extent of their range have already experienced substantial declines in landings with rising ocean temperatures,[170,173,198,199,200] and this pattern is projected to continue in the future (e.g., Cooley et al. 2015, Pershing et al. 2015, Le Bris et al. 2018[39,40,191]). Fishers may need to travel farther to fishing locations for species they currently catch,[189] increasing fuel and crew costs. Distribution shifts (Figure 18.6) can also create opportunities to target new species moving into an area.[155] The impacts and opportunities associated with these changes will not be evenly shared within or among fisheries, fleets, or communities; as such, adaptation may alter social dynamics, cultural ties, and economic benefits.[201,202,203]

Sea Level Rise, Storms, and Flooding

Along the Mid-Atlantic coast (from Cape Hatteras, North Carolina, to Cape Cod, Massachusetts), several decades of tide gauge data through 2009 have shown that sea level rise rates were three to four times higher than the global average rate.[46,205,206] The region's sea level rise rates are increased by land subsidence (sinking)—largely due to vertical land movement related to the melting of glaciers from the last ice age—which leaves much of the land in this region sinking with respect to current sea level.[47,207,208,209] Additionally, shorter-term fluctuations in the variability of ocean dynamics,[210,211] atmospheric shifts,[212,213] and ice mass loss from Greenland and Antarctica[214] have been connected to these recent accelerations in the sea level rise rate in the region. For example, a slowdown of the Gulf Stream during a shorter period of extreme sea level rise observed over 2009–2010 has been linked to a weakening of the Atlantic meridional overturning circulation—the northward flow of upper-level warm, salty waters in the Atlantic (including the Gulf Stream current) and the southward flow of colder, deeper waters.[215] These higher-than-average rates of sea level rise measured in the Northeast have also led to a 100%–200% increase in high tide flooding in some places, causing more persistent and frequent (so-called nuisance flooding) impacts over the last few decades.[44,47,216,217]

Coastal flood risks from storm-driven precipitation and surges are major drivers of coastal change[218,219] and are also amplified by sea level increases.[217,220,221] Storms have unique climatological features in the Northeast—Nor'easters (named for the low-pressure systems typically impacting New England and the Mid-Atlantic with strong northeasterly winds blowing from the ocean over coastal areas) typically occur between September and April, and when coupled with the Atlantic hurricane season between June and September, the region is susceptible to major storms nearly year-round. Storm flood heights driven by hurricanes in New York City increased by more than 3.9 feet (1.2 m) over the last thousand years.[14] When coupled with storm surges, sea level rise can pose severe risks of flooding, with consequent physical and mental health impacts on coastal populations (see Key Messages 4 and 5).

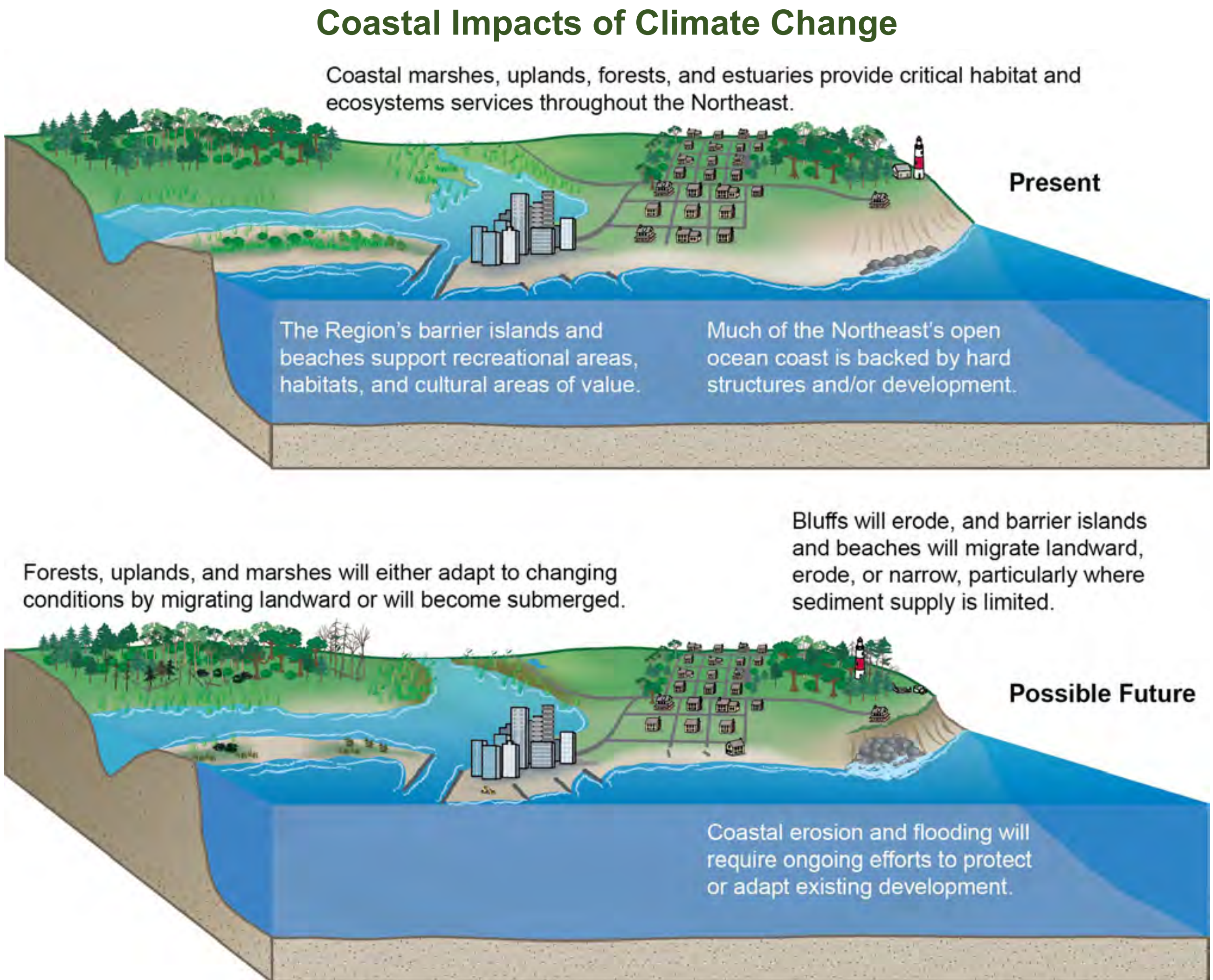

Figure 18.7: (top) The northeastern coastal landscape is composed of uplands and forested areas, wetlands and estuarine systems, mainland and barrier beaches, bluffs, headlands, and rocky shores, as well as developed areas, all of which provide a variety of important services to people and species. (bottom) Future impacts from intense storm activity and sea level rise will vary across the landscape, requiring a variety of adaptation strategies if people, habitats, traditions, and livelihoods are to be protected. Source: U.S. Geological Survey.

Landscape Change and Impacts on Ecosystems Services

Because of the diversity of the Northeast's coastal landscape, the impacts from storms and sea level rise will vary at different locations along the coast (Figure 18.7).[12,13] Rocky and heavily developed coasts have limited infiltration capacity to absorb these impacts, and thus, these low-elevation areas will become gradually inundated.[222,223] However, more dynamic environments, such as mainland and barrier beaches, bluffs, and coastal wetlands, have evolved over thousands of years in response to physical drivers. Such responses include erosion, overwashing, vertical accretion (increasing elevation due to sediment movement), flooding in response to storm events,[218,224,225] and landward migration over the longer term as sea level has risen.[226] Uplands, forests, and agricultural lands can provide transitional areas for these more dynamic settings, wherein the land gradually converts to a tidal marsh.

Varied ecosystem services and natural features have long attracted and sustained people along the coast of the Northeast region. Ecosystem services—including the provisioning of groundwater resources, the filtering of non-point source pollution, sequestering carbon, mitigating storm impacts and erosion, and sustaining working waterfronts and cultural features such as iconic regional landscapes, recreation, and traditions—are facing multiple climate threats. Marshes and beaches serve as the first line of defense for coastal property and infrastructure in the face of storms.[227] They also provide critical habitat for a variety of migratory shorebirds and, when combined with nearshore seagrass and estuaries, serve as nurseries for many commercial marine species.[37,38,150,151,228,229] Regional marshes trap and store carbon[147,230,231,232] and help to capture non-point source pollution before it enters seawater.[233,234,235] Regional beaches are important tourist and recreational attractions, and many coastal national parks and national historic sites throughout the region help preserve cultural heritage and iconic coastal landscapes.[236,237] The Northeast coast is also home to many Indigenous peoples whose traditions and ways of life are deeply tied to land and water (Box 18.2). Coastal tribes often have limited resources, infrastructure, and land ownership, and these limitations can worsen the impacts of climate change and prohibit relocation (Ch. 15: Tribes, KM 1 and 3).

Box 18.2: Indigenous Peoples and Tribal Nations

Indigenous peoples and tribal nations of the Northeast region have millennia-long relationships with the diverse landscapes and climate zones found throughout the region.[238,239,240] Currently, for the 18 federally recognized, numerous state-recognized, and federally unrecognized tribal nations of the Northeast,[241,242] the challenges of adapting to a changing climate add additional uncertainty to existing efforts for reclamation of land and sovereignty and the revitalization of languages and cultures (Ch. 15: Tribes, KM 1 and 3).[97,243] However, in response to a regional shift in the seasons, there has been an increase in climate adaptation work by tribes over the last decade (Ch.15: Tribes, Figure 15.1). These projects have been framed by Indigenous knowledges to address impacts to culturally and economically important resources and species, such as brown ash, sweetgrass, forests, and sugar maple, as well inland and ocean fisheries.[238,244,245,246] These projects provide important results for the tribal nations themselves but could also provide examples of adaptation and survival for other tribal nations and non-tribal communities to consider as they work towards a deeper and more complex engagement to address future landscapes.[97,240] Although not all tribally led climate research and projects across regions have been reported or published, there are even fewer publicly available examples in the Northeast region, and especially for state-recognized and unrecognized tribes. This seems to present itself as a potential future research opportunity for tribal engagement and collaborations in the Northeast (Ch. 15: Tribes).[97]

Projections of Future Sea Level Rise and Coastal Flooding

Projections for the region suggest that sea level rise in the Northeast will be greater than the global average of approximately 0.12 inches (3 mm) per year.[247,248] According to Sweet et al. (2017),[47] the more probable sea level rise scenarios—the Intermediate-Low and Intermediate scenarios from a recent federal interagency sea level rise report (App. 3: Data & Scenarios)—project sea level rise of 2 feet and 4.5 feet (0.6 m and 1.4 m) on average in the region by 2100, respectively.[47] The worst-case and lowest-probability scenarios, however, project that sea levels in the region would rise upwards of 11 feet (3 m) on average by the end of the century.[47] The higher projections for the region as compared with most others in the United States are due to continued changes in oceanic and atmospheric dynamics, thermal expansion, ice melt contributions from Greenland and Antarctica, and ongoing subsidence in the region due to tectonics and non-tectonic effects such as groundwater withdrawal.[47,50,249,250,251,252] Furthermore, the strongest hurricanes are anticipated to become both more frequent and more intense in the future, with greater amounts of precipitation (Ch. 2: Climate, Box 2.5).[50,253,254,255] Thirty-two percent of open-coast north and Mid-Atlantic beaches are predicted to overwash during an intense future nor'easter type storm,[256] a number that increases to more than 80% during a Category 4 hurricane.[257,258]

Future Adaptability of the Coastal Landscape

The dynamic ability of coastal ecosystems to adapt to climate-driven changes depends heavily upon sufficient sediment supply, elevation and slope, barriers to migration,[225] tidal restrictions, wave climatology,[219,259] and the rates of sea level rise. Although nearly 70% of the Northeast coast has some physical ability to dynamically change,[13] an estimated 88% of the Northeast population lives on developed coastal landforms that have limited ability to naturally adapt to sea level rise.[260] Built infrastructure along the coast, such as seawalls, bulkheads, and revetments, as well as natural barriers, such as coastal bluffs, limits landward erosion; jetties and groins interrupt alongshore sediment supply; and culverts and dams create tidal restrictions that can limit habitat suitability for fish communities (see Figure 18.7).[261] An estimated 26% of open ocean coast from Maine to Virginia contains engineering structures.[262] While these structures can help mitigate hazards to people and property, they also reduce the land area for ecosystem migration, as well as the adaptive capacity of natural coastal environments.[43,227,263,264] The ability of marshes in the region to respond to sea level-induced change varies by location, with some areas increasing in elevation, experiencing vegetation shifts, and/or expanding in extent while others are not.[265,266,267,268,269,270,271] Forest diebacks, or "ghost forests," due to wetland encroachment[70,272] are being observed in southern New Jersey and Maryland (Figure 18.8), although one study found that southern New England forests are not showing similar signs of dieback.[273]

Forest Dieback Due to Sea Level Rise

Figure 18.8: Atlantic white cedars dying near the banks of the Bass River in New Jersey show wetland encroachment on forested areas. Photo credit: Ted Blanco/Climate Central.

Projected changes in climate will threaten the integrity of coastal landforms and ecosystems that provide services people and animals rely on and that act as important natural buffers to hazards. Under more extreme scenarios (such as the higher scenario, RCP8.5), marshes are unlikely to survive and, thus, would convert to open water.[224,274,275] At lower rates of sea level rise, marsh health will depend heavily upon site-specific hydrologic, physical, and sediment supply conditions.[259,275,276,277,278] Long-term coastal erosion, as driven by sea level rise and storms, is projected to continue, with one study finding the shoreline likely to erode inland at rates of at least 3.3 feet (1 m) per year among 30% of sandy beaches along the U.S. Atlantic coast.[279] Continued increases in the rate of sea level rise—on the order of 0.08 inches (2 mm) per year above the 20th-century rate—could cause much of the open ocean coasts in the Mid-Atlantic to transition to a state wherein coastal barrier systems migrate landward more rapidly, experience reductions in width or height, and overwash and breach more frequently.[280] Such an increase is projected to occur this century under the Intermediate-Low scenario, which suggests that global sea levels will rise approximately 0.24 inches (6 mm) per year.[47]

An ongoing challenge, now and in the future, is to adequately account for and determine the monetary value of the ecosystem services provided by marine and coastal environments[6,41,281] and to adaptively manage the ecosystems to achieve targets that are responsive to both development and conservation.[282]

These changes to the coastal landscape would threaten the sustainability of communities and their livelihoods. Historical settlement patterns and ongoing development combine to increase the regional vulnerability of coastal communities to sea level rise, coastal storms, and increased inundation during high tides and minor storms. For example, estimates of coastal property losses and protective investments through 2100 due to sea level rise and storm surge vary from less than $15 billion for southeastern Massachusetts to in excess of $30 billion for coastal New Jersey and Delaware under either the lower (RCP4.5) or higher (RCP8.5) scenarios (discounted at 3%).[29] Saltwater intrusion can also impact drinking water supplies, including the alteration of groundwater systems.[283,284] A growing area of research explores potential migration patterns in response to climate-related coastal impacts, where coastal states such as Massachusetts, New Jersey, and New York are anticipated to see large outflows of migrants, a pattern that would stress regional locations further inland.[285] In addition to property and infrastructure impacts (Key Message 3), the facilities and cultural resources that support coastal tourism and recreation (such as parking lots, pavilions, and boardwalks), as well as cultural landscapes and historic structures,[236,237] will be at increased risk from high tide flooding, storm surge, and long-term inundation. In some locations, these culturally and socially important structures also support economic activity; for example, many fishing communities rely on small docks and other shoreside infrastructure for their fishing operations, increasing the risk of substantial disruption if they are lost to sea level rise and increasing storm frequency.[45,286]

Key Message 3

Maintaining Urban Areas and Communities and Their Interconnectedness

The Northeast's urban centers and their interconnections are regional and national hubs for cultural and economic activity. Major negative impacts on critical infrastructure, urban economies, and nationally significant historic sites are already occurring and will become more common with a changing climate.

Climate–Infrastructure Interaction and Heightened Risks

Northeastern cities, with their abundance of concrete and asphalt and relative lack of vegetation, tend to have higher temperatures than surrounding regions due to the urban heat island effect (increased temperatures, typically measured during overnight periods, in highly urbanized areas in comparison to outlying suburban, exurban, and rural locations). During extreme heat events, nighttime temperatures in the region's big cities are generally several degrees higher than surrounding regions, leading to higher risk of heat-related death. In urban areas, the hottest days in the Northeast are also often associated with high concentrations of urban air pollutants including ground-level ozone (Ch. 13: Air Quality, KM 1). This combination of heat stress and poor urban air quality can pose a major health risk to vulnerable groups: young children, elderly, socially or linguistically isolated, economically disadvantaged, and those with preexisting health conditions, including asthma. Vulnerability is further heightened as key infrastructure, including electricity for air conditioning, is more likely to fail precisely when it is most needed—when demand exceeds available supply—with the potential for substantial negative health consequences.[287]

Finally, vulnerability to heat waves is not evenly distributed throughout the region. Rather, outdoor versus indoor air temperatures, baseline health, occupation, and access to air conditioning are important determinants of vulnerability (see Key Message 4).

Urban areas are at risk for large numbers of evacuated and displaced populations and damaged infrastructure due to both extreme precipitation events and recurrent flooding, potentially requiring significant emergency response efforts and consideration of long-term commitment to rebuilding and adaptation, and/or support for relocation where needed. Poor, elderly, historically marginalized, recent immigrants, and linguistically or socially isolated individuals as well as those populations with existing health disparities are more vulnerable to precipitation events and flooding due to a limited ability to prepare for and cope with such events.[59]

Critical Infrastructure Service Disruption

Much of the infrastructure in the Northeast, including drainage and sewer systems, flood and storm protection assets, transportation systems, and power supply, is nearing the end of its planned life expectancy. Current water-related infrastructure in the United States is not designed for the projected wider variability of future climate conditions compared to those recorded in the last century (Ch. 3: Water, KM 2). In order to make Northeast systems resilient to the kind of extreme climate-related disruptions the region has experienced recently—and the sort of disruptions projected for the future—would require significant new investments in infrastructure. For example, in Pennsylvania, bridges are expected to be more prone to damage during extreme weather events, because the state leads the country in the highest percentage of structurally deficient bridges.[288] Pennsylvania's water treatment and wastewater systems are also notably aging, requiring an estimated $28 billion in new investment over the next 20 years for repairs and to meet increasing demands.[288]

Climate-related disruptions will only exacerbate existing issues with aging infrastructure. Sea level rise has amplified storm impacts in the Northeast region (Key Message 2), contributing to higher surges that extend further inland, as demonstrated in New York City.[14,15,16] Sea level rise is leading to an increase in the frequency of coastal flooding, a trend that is projected to grow for cities such as Baltimore and Washington, DC.[289] High tide flooding has increased by a factor of 10 or more over the last 50 years for many cities in the Northeast region and will become increasingly synonymous with regular inundation, exceeding 30 days per year for an estimated 20 cities by 2050 even under a very low scenario (RCP2.6).[216] More frequent high tide flooding (also referred to as nuisance, or sunny day, flooding) will be experienced at low-elevation cities and towns in the region (Figure 18.9). Sea level rise (see Key Message 2) under higher scenarios will likely increase property losses from hurricanes and other coastal storms for the region by \$6–\$9 billion per year by 2100, while changes in hurricane activity could raise these estimates to \$11–\$17 billion per year.[260] In other words, projected future costs are estimated to continue along a steep upward trend relative to what is being experienced today. However, there is limited published

King Tide Flooding in Northeast

Figure 18.9: The photo shows king tide flooding on Dock Street in Annapolis, Maryland, on December 21, 2012. Photo credit: Amy McGovern (CC BY 2.0).

research that quantifies the costs associated with increased damage across an entire system in response to amplified storm events. Actions to replace and/or significantly modify the Northeast's aging infrastructure provide opportunities to incorporate climate change adaptation and resilience into standard capital upgrades, reducing these future costs.

Impacts on Urban Economies

Service and resource supply infrastructure in the Northeast region is at increasing risk of disruption, resulting in lower quality of life, economic declines, and increased social inequality.[17] Loss of public services affects the capacity of communities to function as administrative and economic centers and triggers disruptions of interconnected supply chains (Ch. 16: International, KM 1). Interdependencies across critical infrastructure sectors such as water, energy, transportation, and telecommunication can lead to cascading failures during extreme weather and climate-related disruptions,[17,59] as occurred during the 2003 blackout in New York City (Ch. 17: Complex Systems, Box 17.5; Ch. 11: Urban). For example, the Northeast is projected to experience a significant increase in summer heat and the number and/or duration of heat waves that will further stress summertime energy peak

Mitigation in the Northeast

The Northeast region has traditionally been a leader in greenhouse gas mitigation action, serving as a potential model for other states. The Regional Greenhouse Gas Initiative is the first mandatory market-based program in the United States to cap and reduce CO_2 emissions from the power sector through a cooperative effort among Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont.

load demands from higher air conditioning use and the greater need to pump and treat water. Energy supply failures can also affect transportation operations, and even after electricity is restored, a significant time lag can occur until transportation services such as subway signals and traffic lights return to operation.[290] Understanding and coping with these interdependencies require cross-sector analysis and engagement by the private sector and within and across different levels of government. As a result, the connection between climate impacts, adaptation, and sustained economic development of cities is a major concern in the region.

The large number of manufacturing, distribution, and storage facilities, as well as historic structures, in the region are also vulnerable to climate shifts and extremes. For example, power plants in New York City tend to be located along the coastline for easy access to water for cooling and maritime-delivered fuel and are often located within about 16 feet (5 m) of sea level.[59] This is not unusual, as there are many power plants and petroleum storage facilities located along the Northeast coastline.[291]

The historic preservation community has begun to address the issue of climate change.[292,293] Many historic districts in cities and towns, such as Annapolis, Maryland, and Newport, Rhode Island, are at low elevations along the coast and now face the threat of rising sea levels.

Preparedness in Cities and Towns

Projected increases in coastal flooding, heavy precipitation, runoff, and extreme heat would have negative impacts on urban centers with disproportionate effects on at-risk communities. Larger cities, including Boston, MA, Burlington, VT, Hartford, CT, Newark, NJ, Manchester, NH, New York, Philadelphia, PA, Pittsburgh, PA, Portland, ME, Providence, RI, and Washington, DC, have begun to plan for climate change and in some instances have started to implement action, particularly when upgrading aging infrastructure (e.g., NYC Special Initiative for Rebuilding and Resiliency 2013, Climate Ready Boston 2016, City of Philadelphia 2016, City of Pittsburgh 2017[294,295,296,297]). Examples from municipalities of varying sizes are common (e.g., U.S. EPA 2017[33]). These cities seek to maintain the within-city and intercity connectivity that fosters growth, diversity, liveliness of urban neighborhoods, and protection of vulnerable populations, including the elderly, young, and disadvantaged. Further, city leaders hope to avoid forced migration of highly vulnerable populations and the loss of historical and cultural resources. City managers and stakeholders recognize that extreme heat events, sea level rise, and storm surge have the potential to lead to complex disasters and sustained critical infrastructure damage. Specific actions cities are taking focus largely on promoting the resilience of critical infrastructure, enhancing the social resilience of communities (especially of vulnerable populations), promoting ecosystem service hazard mitigation, and developing new indicators and monitoring systems to achieve a better understanding of climate risks and to identify adaptation strategies (see Key Message 5) (see also Ch. 11: Urban). In the Northeast region, Superstorm Sandy illustrated urban coastal flooding risk, and many localities, not just those directly impacted by the storm, have developed increased coastal resilience plans and efforts. New York City has been able to put in place a broad set of efforts in a variety of critical infrastructure sectors, including making the subway more protected from flooding (Figure 18.10).

Subway Air Vent Flood Protection

Figure 18.10: The photo shows a subway air vent with a multiuse raised flood protection grate that was installed as part of the post–Superstorm Sandy coastal resilience efforts on West Broadway in lower Manhattan, New York City. Photo credit: William Solecki.

Many Northeast cities are served by combined sewer systems that collect and treat both storm water and municipal wastewater. During heavy rain events, combined systems can be overwhelmed and release untreated sewage into local bodies of water.[298] Moderate flooding events are expected to become more frequent in most of the Northeast during the 21st century because of more intense precipitation related to climate change.[58,142] Finally, increased precipitation and high streamflows also increase streambed erosion, especially when coupled with wetter soils prior to storm events.[299,300] Erosion at bridges can cause bridge failures,[301] leading to transportation disruption, injuries, and potential fatalities.

The impacts of changes in precipitation and temperature on water supply system behavior in the Northeast are complex. Future potable water supplies are expected to be adequate to meet future demand on average across the Northeast, but the number of watersheds where demand exceeds supply is projected to increase under most climate change scenarios.[302] Studies of specific water systems in the Northeast show mixed results. The New York City reservoir system shows high resilience and reliability under different climate change scenarios.[303] Projected flows in the Potomac River, the primary water supply for the Washington, DC, metropolitan area, are lower in most climate change scenarios, with minor to major impacts on water supply.[304]

Key Message 4

Threats to Human Health

Changing climate threatens the health and well-being of people in the Northeast through more extreme weather, warmer temperatures, degradation of air and water quality, and sea level rise. These environmental changes are expected to lead to health-related impacts and costs, including additional deaths, emergency room visits and hospitalizations, and a lower quality of life. Health impacts are expected to vary by location, age, current health, and other characteristics of individuals and communities.

Health Effects of Extreme Heat

Present-day high temperatures (heat) have been conclusively linked to a higher risk of illness and death, particularly among older adults, pregnant women, and children (Ch 14: Human Health). A number of studies have replicated these findings specifically in the Northeast (see Box 18.3; e.g., Wellenius et al. 2017, Bobb et al. 2014, Hondula et al. 2012[305,306,307]). Ambient temperatures and heat-related health effects can vary significantly over small geographic areas due to local land cover (for example, due to the urban heat island effect; see Key Message 3) (see also Ch. 5: Land Changes, KM 1), topography, and the resilience of individuals and communities.[307,308] For example, older or sicker individuals and those persons who are without access to air conditioning, living in older homes, socially isolated, or working outdoors are considered particularly vulnerable to the effects of heat.[309,310,311]

Annual average temperature over the contiguous United States has increased by 1.2°F (0.7°C) over the last few decades and by 1.8°F (1.0°C) relative to the beginning of the last century. Recent decades are the warmest in at least the past 1,500 years.[312] Average annual temperatures across the Northeast have increased from less than 1°F (0.6°C) in West Virginia to about 3°F (1.7°C) or more in New England since 1901.[18,19] Although the relative risk of death on very hot days is lower today than it was a few decades ago, heat-related illness and death remain significant public health problems in the Northeast.[20,21,22,23] For example, a study in New York City estimated that in 2013 there were 133 excess deaths due to extreme heat.[24]

Annual average temperature in the contiguous United States is expected to increase by an additional 2.5°F (1.4°C) over the next few decades regardless of future greenhouse gas emissions (Ch 2: Climate).[50] By 2050, average annual temperatures in the Northeast are expected to increase by 4.0°F (2.2°C) under the lower scenario (RCP4.5) and 5.1°F (2.8°C) under the higher scenario (RCP8.5) relative to the near present (1975–2005),[50] with several more days of extreme heat occurring throughout the region each year.

These projected increases in temperature are expected to lead to substantially more premature deaths, hospital admissions, and emergency department visits due to heat across the Northeast.[23,25,26,27,28,29] For example, in the Northeast we can expect approximately 650 more excess deaths per year caused by extreme heat by 2050 under either a lower or higher scenario (RCP4.5 or RCP8.5) and 960 (under RCP4.5) to 2,300 (under RCP8.5) more excess deaths per year by 2090.[29]

The risks associated with present-day and projected future heat can be minimized by reducing greenhouse gas emissions, minimizing exposure through urban design, or increasing individual and community resilience.[23,29,313] For example, in the Northeast region, Philadelphia and New York City have been leaders in implementing policies and investing in infrastructure aimed at reducing the number of excess deaths from extreme heat.[314] Compared to the higher scenario (RCP8.5), 1,400 premature deaths from extreme temperatures could be avoided in the Northeast each year by 2090 if global greenhouse gas emissions are consistent with the lower scenario (RCP4.5), resulting in $21 billion in annual savings (in 2015 dollars).[29]

Box 18.3: Rising Temperatures and Heat-Related Emergency Room Visits in Rhode Island

Moderate and extreme heat events already pose a health risk today,[305,306,315,316] and climate change could increase this risk. Of note, days of moderate heat occur much more often compared to days of extreme heat, such that days of moderate heat may, in aggregate, be associated with a larger number of adverse health events.[315] Average summertime temperatures are projected to continue to rise through the end of the century, raising concern about the public health impact of climate change across Northeast communities. A nationwide study projected that some of the largest increases in heat-related mortality would occur in the Northeast region, with an additional 50–100 heat-related deaths per year per million people by 2050 and 120–180 additional deaths per million people by 2100 under the mid-high scenario (RCP6.0).[28] Heat health risks seem to be highest at the start of the warm weather each year[317] and among vulnerable populations such as outdoor workers, young children, and the elderly.

Box 18.3: Rising Temperatures and Heat-Related Emergency Room Visits in Rhode Island, *continued*

In the small, coastal northeastern state of Rhode Island (population of about 1 million), maximum daily temperatures in the summer have trended upwards over the last 60 years such that Rhode Islanders experienced about three more weeks of uncomfortably hot weather over 2015–2016 than in the 1950s (Figure 18.11, left panel). A recent study looking at visits to hospital emergency rooms (ERs) found that the risk of heat-related ER visits increased sharply as maximum daily temperatures climbed above 80°F (Figure 18.11, middle panel).[26] The researchers projected that with continued climate change, Rhode Islanders could experience an additional 400 (6.8% more) heat-related ER visits each year by 2050 and up to an additional 1,500 (24.4% more) such visits each year by 2095 under the higher scenario (RCP8.5; Figure 18.11, right panel). Importantly, about 1,000 fewer annual heat-related ER visits are projected for the end of the century under the lower scenario (RCP4.5) compared to the higher scenario (RCP8.5), representing the potential protective benefit of limiting greenhouse gas emissions. Such reductions would also lead to improvements in air pollution and health starting today.[318,319]

In response to the health threat from heat, local National Weather Service offices issue heat advisories and excessive heat warnings when the forecast calls for very hot weather. Based on the results of a study across multiple states,[305] the National Weather Service Northeast Region updated its heat advisory guidelines to be issued when the heat index is forecast to exceed 95°F for any amount of time on two or more days or 100°F for any amount of time on a single day. Many communities in the Northeast have implemented plans to respond to these heat alerts to better protect the public's health (for example, with the Centers for Disease Control and Prevention's Building Resilience Against Climate Effects program), although gaps in knowledge remain.[34,314] Uncertainties exist in the estimation of the cumulative impact on health of multiple aspects of weather, including heat, drought,[320] and heavy precipitation,[321,322,323] all of which have potential adverse impacts on human health.

Observed and Projected Impacts of Excess Heat on Emergency Room Visits in Rhode Island

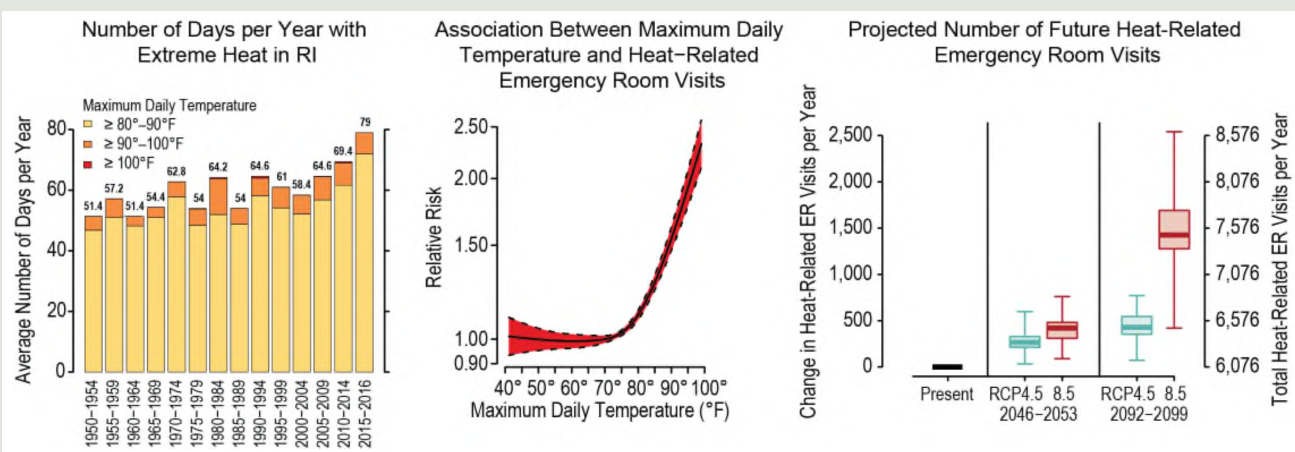

Figure 18.11: This figure shows the observed and projected impacts of excess heat on emergency room visits in Rhode Island. (left) In Rhode Island, maximum daily temperatures in the summer have trended upwards over the last 60 years, such that residents experienced about three more weeks of health-threatening hot weather over 2015–2016 than in the 1950s. (middle) A recent study looking at visits to hospital emergency rooms (ERs) found that the incidence rate of heat-related ER visits rose sharply as maximum daily temperatures climbed above 80°F. (right) The study estimates that with continued climate change, Rhode Islanders could experience an additional 400 (6.8% more) heat-related ER visits each year by 2050 and up to an additional 1,500 (24.4% more) such visits each year by 2095 under the higher scenario (RCP8.5). About 1,000 fewer annual heat-related ER visits are projected for the end of the century under the lower scenario (RCP4.5) compared to the higher scenario (RCP8.5), reflecting the estimated health benefits of adhering to a lower greenhouse gas emissions scenario. Sources: (left) Brown University; (middle, right) adapted from Kingsley et al. 2016.[26] Reproduced from Environmental Health Perspectives.

Health Effects of Air Pollution, Aeroallergens, and Wildfires

Climate change is increasing the risk of illness and death due to higher concentrations of air pollutants in many parts of the United States (Ch. 13: Air Quality). In the Northeast, climate change threatens to reverse improvements in air quality that have been achieved over the past couple of decades. For example, climate change is projected to influence future levels of ground-level ozone pollution in the Northeast by altering weather conditions and impacting emissions from human and natural sources.[324,325,326] This "climate penalty," whereby reductions in ozone precursor emissions are at least partially offset by a changing climate, is projected to lead to substantially more ozone pollution-related deaths;[324,325,29] 200–300 more excess deaths per year by 2050 compared to 2000 by one estimate.[325]

Excess deaths due to ground-level ozone pollution are projected to increase substantially under both lower (RCP4.5) and higher (RCP8.5) scenarios.[29] Reducing global emissions of greenhouse gases from a higher scenario to a lower scenario could prevent approximately 360 deaths per year due to air quality in 2090, saving approximately $5.3 billion per year (in 2015 dollars, undiscounted).[327] Moreover, many sources of the greenhouse gas emissions that contribute to climate change also contribute to degraded air quality today, with adverse effects on people's health. The adverse health risks from air pollution can be reduced in the present and in the future by addressing these common emission sources.[319]

More frequent and severe wildfires due to climate change pose an increasing risk to human health through impacts on air quality (Ch. 13: Air Quality, KM 2). Wildfire smoke can travel hundreds of miles, as occurred in 2015 when Canadian wildfire smoke caused air quality exceedance days in Baltimore, Maryland.[328]

Climate change is also expected to lengthen and intensify pollen seasons in parts of the United States, potentially leading to additional cases of allergic rhinitis (also known as hay fever) and allergic asthma episodes (Ch. 13: Air Quality, KM 3).[29,329] Among individuals with allergic asthma, exposure to certain types of pollen can result in worsening of symptoms leading to increases in allergy medication sales and emergency room visits for asthma, as already documented in New York City.[330]

Indoors, climate change is expected to bring conditions that foster mold growth, such as more dampness, and more frequent power outages that impair ventilation. Damp indoor conditions and mold are both known to be associated with respiratory illnesses including asthma symptoms and wheezing.[331] When damp conditions occur in buildings, rapid action could be warranted—remediation in a northeastern office building after the development of respiratory or severe non-respiratory symptoms by building inhabitants was not effective in reducing symptoms.[332]

Changing Ecosystems and Risk of Vector-Borne Disease

The risk posed by vector-borne diseases (those transmitted by disease-carriers such as fleas, ticks, and mosquitoes) such as Lyme disease and West Nile virus under a changing climate is also of concern in the Northeast region. These diseases, specifically tick-related Lyme disease, have been linked to climate, particularly with abundant late-spring and early-summer moisture. By 2065–2080, under the higher scenario (RCP8.5) it is projected that the period of elevated risk of Lyme disease transmission in the Northeast will begin 0.9–2.8 weeks earlier between Maine and Pennsylvania, compared to the climate observed over 1992–2007).[67] Similarly, a recent analysis estimates that there would be an additional 490 cases of West Nile neuroinvasive disease per year in the Northeast by 2090 under the higher scenario (RCP8.5) versus 210 additional cases per year under the lower scenario (RCP4.5).[29] The geographic range of suitable habitats for other mosquito vectors such as the northern house mosquito (*Culex pipiens* and *Culex restuans*, which transmit West Nile virus) and the Asian tiger mosquito (*Aedes albopictus*, which can also transmit West Nile virus and other mosquito-borne diseases) is expected to continue shifting northward into New England in the next several decades and through the end of the century as a result of climate change.[333,334]

Gastrointestinal Illness from Waterborne and Foodborne Contaminants

Another consequence of climate change is the spread of marine toxins and pathogens (Key Message 2). Some of these pathogens pose health risks through consumption of contaminated seafood. Harmful algal blooms, which can cause paralytic shellfish poisoning in humans, have become more frequent and longer lasting in the Gulf of Maine.[335] Similarly, pathogenic strains of the waterborne bacteria *Vibrio*—which are already causing thousands of foodborne illnesses per year—have expanded northward and have been responsible for increasing cases of illness in oyster consumers in the Northeast region.[336,337,338]

Combined sewer systems (where municipal wastewater and storm water use the same pipes) are particularly common in the Northeast given the older infrastructure typical of the region.[339] When runoff from heavy precipitation exceeds the capacity of these systems, combined sewer overflow containing untreated sewage is released into local waterways, potentially impacting the quality of water used for recreation or drinking. For example, a study in Massachusetts found an increased risk of gastrointestinal illness with heavy precipitation causing combined sewer overflows.[322] Increased risk of campylobacteriosis and salmonella has been documented in Maryland with increased heavy precipitation and streamflows.[340,341] Moderate flooding events are expected to become more frequent in most of the Northeast during the 21st century because of more intense precipitation related to climate change.[105,142] This could, therefore, increase the frequency of combined sewer overflows and waterborne disease. Some cities and towns are making substantial investments to reduce or eliminate the risks of combined sewer overflows (Figure 18.12).

Storm-related power outages can also pose a risk of foodborne illness.[343] Increased diarrheal illnesses from consumption of spoiled food have also been documented in New York City in 2003 following a power outage that affected millions in the Northeast (Ch. 17: Complex Systems, Box 17.5).[344]

District of Columbia Water and Sewer Authority's Clean Rivers Project

Figure 18.12: The District of Columbia Water and Sewer Authority's Clean Rivers Project[342] aims to reduce combined sewer overflows into area waterways. The Clean Rivers Project is expected to reduce overflows annually by 96% throughout the system and by 98% for the Anacostia River. In addition, the project is expected to reduce the chance of flooding in the areas it serves from approximately 50% to 7% in any given year and reduce nitrogen discharged to the Chesapeake Bay by approximately 1 million pounds per year. Photo credit: Daniel Lobo (CC BY 2.0).

Box 18.4: Role of Public Health and Healthcare Sector in Resilience and Prevention

There are numerous examples of how the public health and healthcare sectors are preparing for climate change and making energy saving changes, as highlighted in the U.S. Department of Health and Human Services' report on enhancing healthcare resilience.[345] One such example occurred in Greenwich, Connecticut, where Greenwich Hospital installed a combined heat and power system that conserves energy and provided stability in the wake of Superstorm Sandy.[346]

In June 2016, severe flooding in West Virginia resulted from a "thousand-year storm"[347] and highlighted the important role of the healthcare sector in building resilience to extreme precipitation events. A recent study of the event described the role of state and federal government working in partnership with healthcare volunteer organizations to effectively mobilize a response in the setting of such a disaster.[348] It emphasized the critical importance of healthcare professionals in providing emotional and mental health support to the response volunteers and the affected communities, as well as a need to increase capacity in these areas.[348] See Key Message 5 in this chapter and Chapter 14: Human Health, Key Message 3 for more information on additional adaptation efforts that protect health.

Figure 18.13: A Red Cross volunteer talks with a community resident after the 2016 West Virginia floods. Additionally, local medical professionals mobilized to staff temporary clinical sites. Photo credit: National Guard Bureau Public Affairs.

Mental Health and Well-Being

In addition to the adverse impacts on people's physical health, climate change is also associated with adverse impacts on mental health (Ch. 14: Human Health, KM 1). Specifically in the Northeast region, sea level rise, storm surge, and extreme precipitation events associated with climate change will contribute to higher risk of flooding in both coastal and inland areas—particularly in urban areas with large amounts of impervious surface that increases water runoff. In addition to the risks of physical injury, waterborne disease, and healthcare service disruption caused by flooding, lasting mental health consequences, such as anxiety, depression, and post-traumatic stress disorder can impact affected communities, as was observed in the wake of Superstorm Sandy in 2012 (Box 18.4).[349] Extreme weather events can have both immediate, short-term effects, as well as longer-term impacts on mental health and well-being that can last years after the specific event.

Extreme heat can also affect mental health and well-being. Higher outdoor temperatures are associated with decreases in subtle aspects of well-being such as decreased joy and happiness[350] and increased aggression and violence.[351] Underlying mental health conditions and geography also affect vulnerability. For example, a study of hospitalization for heat-related illness among people with mental health disorders showed increased risk in rural versus urban areas, possibly due to lower availability of mental health services in these rural areas.[352]

Separately, large population changes from climate-driven human migration could substantially influence both coastal and inland communities in the Northeast region (see also Key Messages 2 and 5).[285] The impacts of human migration on health and well-being depend on myriad factors, including the context of the migration.[353]

Regional Variation in Health Impacts and Vulnerability

Although climate change affects all residents of the Northeast region, risks are not experienced equally. The impact of climate change on an individual depends on the degree of exposure, the individual sensitivity to that exposure, and the individual or community-level capacity to recover (Ch. 14: Human Health, KM 2).[354] Thus, health impacts of climate change will vary across people and communities of the Northeast region depending on social, socioeconomic, demographic, and societal factors; community adaptation efforts; and underlying individual vulnerability (see Key Message 5) (see also Ch. 28: Adaptation). Particularly vulnerable groups include older or socially isolated adults, children, low-income communities, and communities of color.

Key Message 5

Adaptation to Climate Change Is Underway

Communities in the Northeast are proactively planning and implementing actions to reduce risks posed by climate change. Using decision support tools to develop and apply adaptation strategies informs both the value of adopting solutions and the remaining challenges. Experience since the last assessment provides a foundation to advance future adaptation efforts.

Communities, towns, cities, counties, states, and tribes across the Northeast are engaged in efforts to build resilience to environmental challenges and adapt to a changing climate. Developing and implementing climate adaptation strategies in daily practice often occur in collaboration with state and federal agencies (e.g., New Jersey Climate Adaptation Alliance, New York Climate Clearinghouse, Massachusetts StormSmart Coasts and Climate Action Tool, Rhode Island StormTools, EPA, CDC).[30,31,32,33,34,355,356] Advances in rural towns, cities, and suburban areas include low-cost adjustments of existing building codes and standards. In coastal areas, partnerships among local communities and federal and state agencies leverage federal adaptation tools and decision support frameworks (the National Oceanic and Atmospheric Administration's [NOAA] Digital Coast, the U.S. Geological Survey's [USGS] Coastal Change Hazards Portal, New Jersey's Getting to Resilience).

Increasingly, cities and towns across the Northeast region are developing or implementing plans for adaptation and resilience in the face of a changing climate (e.g., EPA 2017[33]). These approaches are designed to maintain and enhance the everyday life of residents and promote economic development. In some cities, adaptation planning has been used to respond to present and future challenges in the built environment. Regional efforts have recommended changes in design standards when building, replacing, or retrofitting infrastructure to account for a changing climate (Box 18.5). For example, the Port Authority of New York and New Jersey provided guidelines for engineers to account for projected changes in temperature, precipitation, and sea level rise when designing infrastructure assets.[357] The cities of Philadelphia, Pennsylvania,[296] Utica, New York,[358] and Boston, Massachusetts,[295] promote the use of green infrastructure to build resilience, particularly in response to flooding risk (Ch. 8: Coastal, Figure 8.2). In Jamaica Bay, New York, post–Superstorm Sandy efforts have fostered a set of local, regional, state, and federal actions that link resilience efforts to current climate risk, along with the potential for accelerated sea level rise and its implications for increased flood frequency (Ch. 28: Adaptation, KM 1).[359]

The issue of water security has emerged from vulnerability assessments and cuts across urban and rural communities. One example is the Washington, DC, metropolitan area's potential use of the Potomac and Occoquan estuaries as water supplies and of retired quarries as water storage facilities.[304] Adaptive reservoir operations have been implemented in the Northeast and other regions of the United States to better manage plausible future climate conditions and to meet other management goals (Ch. 3: Water, KM 3). Tribal nations have also focused on adaptation and the vulnerability of their water supplies, based on long-standing local values and traditional knowledge, including the use of water for drinking, habitat for fish and wildlife, agriculture, and cultural purposes.[97,360,361]

While resilience efforts have focused on microscale adaptations to current climate risks, communities are increasingly seeing a need for larger-scale adaptation efforts. Wide disparities in adaptive capacity exist among communities in the region. Larger, often better-resourced communities have created climate offices and programs, while response has lagged in smaller or poorer communities that are often more dependent on county- or state-level programs and expertise. The move from small-scale to larger-scale and more transformative adaptation efforts involves complex policy transition planning, social and economic development, and equity considerations (Ch. 28: Adaptation, KM 4).[362,363] This includes attention to community concerns about green gentrification—the practice of making environmental improvements in urban areas—that generally increases property values but often also drives out lower-income residents.[364]

Box 18.5: Adapting the Northeast's Cultural Heritage

A defining characteristic of the Northeast region is its rich, dense record of cultural heritage, marked by historic structures, archaeological sites, and cultural landscapes. The ability to preserve this cultural heritage is challenged by climate change. National parks and historic sites in the Northeast are already witnessing cultural resource impacts from climate change, and more impacts are expected in the future.[236] These cultural resources present unique adaptation challenges, and the region is moving forward with planning for future adaptation.

Superstorm Sandy caused substantial damage to coastal New York Harbor parks, including Gateway National Recreation Area and Statue of Liberty National Monument, where buildings and the landscape surrounding the statue and on Ellis Island were impacted and the museum collections were threatened by the loss of climate control systems that were flooded.[370,371] Sea level rise amplifies the impacts of storm events such as Superstorm Sandy, and the parks are using recovery as an opportunity to rebuild with more resilience to future storms.[371,372,373] Heating and electrical systems in historic buildings have been elevated from basement levels. Design changes, such as using non-mold-growing materials and other engineering solutions, have been made while maintaining the buildings' historic character. Following the storm, Gateway National Recreation Area added climate change vulnerability to their planning process for prioritizing historic structures between preserve, stabilize, or ruin. The recreation area has been implementing these priorities as part of the recovery process, providing examples of climate adaptation implementation.[359,374] The human community on Rockaways peninsula also responded to Sandy by using urban forestry and agricultural practices to recover and to buffer against the impact of future storms (see Building Resiliency at the Rockaways 360 tour[375]).

Decision Support Tools and Adaptation Actions

While adaptation is progressing in a variety of forms in the Northeast region, many efforts have focused on assessing risks and developing decision support tools. Many of these assessments and tools have proven useful for specific purposes. Structured decision-making is where decision-makers engage at the outset to define a problem, objectives, alternative management actions, and the consequences and tradeoffs of such actions—before making any decisions. It is being increasingly applied to design management plans, determine research needs, and allocate resources to preserve habitat and resources throughout the region.[151,365,366,367] There has been little attention devoted to evaluating and communicating the suitability and robustness of the many tools that are now available. Efforts to evaluate decision support tools and processes in a rigorous scientific manner would help stakeholders choose the best tools to answer particular questions under specific circumstances.

One significant advancement that communities and infrastructure managers have made in recent years has been the development of risk, impact, and adaptation indicators, as well as monitoring systems to measure and understand climate change and its impacts.[15] In recognizing the economic impacts of infrastructure service loss and disruption, government agencies have begun adaptation analyses to identify those infrastructure elements most critical for regional economic resilience during climate-related disruptions, as well as to identify communities most exposed to acute and chronic climate risks.[45,368,369]

Resource managers, community leaders, and other stakeholders are altering the management of coastal areas and resources in the context of climate change (Boxes 18.6 and 18.7).

Box 18.6: Building Resilience in the Chesapeake Bay Watershed

The Chesapeake Bay watershed is experiencing stronger and more frequent storms, an increase in heavy precipitation events, increasing bay water temperatures, and a rise in sea level. These trends vary throughout the watershed and over time but are expected to continue over the next century under all scenarios considered. The trends are altering both the ecosystems and mainland and island communities of the Chesapeake Bay watershed. Achieving watershed goals would require changes in policies, programs, and/or projects to achieve restoration, sustainability, conservation, and protection goals for the entire system.

To gain a better understanding of the likely impacts of climate change, as well as potential management solutions for the watershed, the 2014 Chesapeake Bay Watershed Agreement committed the NOAA Chesapeake Bay Program (CBP) Partnership to take action to "increase the resiliency of the Chesapeake Bay watershed, including its living resources, habitats, public infrastructure and communities, to withstand adverse impacts from changing environmental and climate conditions." This new Bay Agreement goal builds on the 2010 Total Maximum Daily Load (TMDL) documentation and 2009 Presidential Executive Order 13508[376,377] that called for an assessment of the impacts of a changing climate on the Chesapeake Bay's water quality and living resources. To achieve this goal and regulatory mandates, the CBP Partnership is undertaking efforts to monitor and assess trends and likely impacts of changing climatic and sea level conditions on the Chesapeake Bay ecosystem and to pursue, design, and construct restoration and protection projects to enhance resilience. The CBP Climate

Box 18.6: Building Resilience in the Chesapeake Bay Watershed, *continued*

Resiliency Workgroup's Management Strategy recognizes that it is important to build community and institutional capacity and to develop analytical capability to build cross-science disciplinary knowledge and better understanding of societal responses. A significant activity now underway is geared towards the midpoint assessment of progress towards the 2025 Chesapeake Bay TMDL goal for water quality standard attainment. As part of the TMDL midpoint assessment, the CBP Partnership has developed tools and procedures to quantify the effects of climate change on watershed flows and pollutant loads, storm intensity, increased estuarine temperatures, sea level rise, and ecosystem influences, including loss of tidal wetland attenuation with sea level rise. Current modeling efforts are underway to assess potential climate change impacts under a range of projected climate change outcomes for 2025 and 2050.[378]

Addressing climate change within the context of established watershed planning and regulatory efforts is extremely complex and requires sound climate science, climate assessments, modeling, policy development, and stakeholder engagement (Ch. 28: Adaptation, Figure 28.1). The CBP Partnership is tackling this challenge on all of these fronts, with priority directed to understanding what is needed to achieve the 2025 nutrient reduction goals and the best management practices required to achieve climate-resilient rehabilitation goals.

For example, research in Delaware is exploring the use of seashore mallow as a transitional salt-tolerant crop because of gradual wetland migration onto agricultural lands as sea levels rise.[379] Commercial and recreational fisheries and tourism depend upon living marine resources. Climate adaptation in ocean fisheries will entail coping and long-term planning responses at multiple levels of communities, industry, and management systems.[380] Fishers have traditionally switched species as needed based on ecosystem or market conditions; this will continue to be an important adaptation option, but it is increasingly constrained by regulatory approaches in fisheries.[155,178,179,202] Longer-term planning for climate adaptation has included state commissions to evaluate ocean acidification threats,[381,382] federal efforts to articulate science strategies,[383,384,385] species vulnerability assessments,[143,186] coupled social–ecological vulnerability assessments for fishing communities,[45] and planning for the potential inland migration of coastal populations due to sea level rise.[386]

The winter recreation industry has long considered snowmaking an adaptation to climate change.[387] Snowmaking improvements should assist with the viability of some Northeast ski areas,[117] while new tourism opportunities emerge.[388]

In order to sustain and advance these and other planned efforts towards climate change adaptation and resilience, decision-makers in the Northeast need to be aware of existing constraints and emerging issues. Constraints from the management, economic, and social context are highly uncertain.[389] These efforts have faced a variety of barriers and limitations, including lack of funding and jurisdictional and legal constraints.[390,391] In many cases, adaptation has been limited to coping responses that address short-term needs and are feasible within the current institutional context, whereas longer-term, more transformative efforts will likely require complex policy transition planning and frameworks that can address social and economic equality.[363] The need for solutions that support industry and community flexibility in responding to climate-related changes has also been recognized.[45,178]

Earth's changing climate is one of several stressors on human and natural systems, and it can work to exacerbate existing vulnerabilities and inequalities. Implementing resilience planning and climate change adaptation in

Box 18.7: Science for Balancing Wildlife and Human Needs in the Face of Sea Level Rise

Policymakers, agencies, and natural resource managers are under increasing pressure to manage coastal areas to meet social, economic, and natural resource demands, particularly as sea levels rise. Scientific knowledge of coastal processes and habitat use can support decision-makers as they balance these often-conflicting human and ecological needs. In collaboration with a wide network of natural resource professionals from state and federal agencies (including the U.S. Fish and Wildlife Service and National Park Service) and private conservation organizations, a research team from the U.S. Geological Survey (USGS) is conducting research and developing tools to identify suitable coastal habitats for species of concern, such as the piping plover (*Charadrius melodus*)—an ecologically important species with low population numbers—under a variety of sea level rise scenarios.

The multidisciplinary USGS team uses historical and current habitat availability and coastal characteristics to develop models that forecast likely future habitat from Maine to North Carolina.[392,393] The collaborative partners, both researchers and managers, are critical to the program: they aid in data collection efforts through the "iPlover" smartphone application[394] and help scientists focus research on specific management questions. Because these shorebirds favor sandy beaches that overwash frequently during storms, the resulting habitat maps also define current and future areas of high hazard exposure for humans and infrastructure.

Land-use planners can use results to determine optimal locations for constructing recreational facilities that minimize impacts on sensitive habitats and have a low probability of being overwashed. Alternatively, results can help resource managers proactively protect the highest-quality habitats to meet near- and long-term conservation goals and, in so doing, increase beach access for users by reducing human–bird conflicts and improving the certainty of beach availability for recreational use.

(a)

(b)

(c)

Figure 18.14: (a, b) These photographs show suitable piping plover habitat for (c) rearing chicks along the U.S. Atlantic coast. Photo credits: (a, b) Sara Zeigler, U.S. Geological Survey; (c) Josh Seibel, U.S. Fish and Wildlife Service.

order to preserve the cultural, economic, and natural heritage of the Northeast would require ongoing collaboration among tribal, rural, and urban communities as well as municipal, state, tribal, and federal agencies. The number and scope of existing adaptation plans in the Northeast show that many people in the region consider this heritage to be important.

Acknowledgments

Technical Contributors

Zoe P. Johnson,
U.S. Department of Defense, Naval Facilities Engineering Command (formerly NOAA Chesapeake Bay Office)

Amanda Babson
U.S. National Park Service

Elizabeth Pendleton
U.S. Geological Survey

Benjamin T. Gutierrez
U.S. Geological Survey

Joseph Salisbury
University of New Hampshire

Andrew Sven McCall Jr.
University of Vermont

E. Robert Thieler
U.S. Geological Survey

Sara L. Zeigler
U.S. Geological Survey

USGCRP Coordinators

Christopher W. Avery
Senior Manager

Matthew Dzaugis
Program Coordinator

Allyza Lustig
Program Coordinator

Opening Image Credit

Bartram Bridge: © Thomas James Caldwell/Flickr (CC BY-SA 2.0). Adaptation: cropped top and bottom to conform to the size needed for publication.

Traceable Accounts

Process Description

It is understood that authors for a regional assessment must have scientific and regional credibility in the topical areas. Each author must also be willing and interested in serving in this capacity. Author selection for the Northeast chapter proceeded as follows:

First, the U.S. Global Change Research Program (USGCRP) released a Call for Public Nominations. Interested scientists were either nominated or self-nominated and their names placed into a database. The concurrent USGCRP Call for Public Nominations also solicited scientists to serve as chapter leads. Both lists were reviewed by the USGCRP with input from the coordinating lead author (CLA) and from the National Climate Assessment (NCA) Steering Committee. All regional chapter lead (CL) authors were selected by the USGCRP at the same time. The CLA and CL then convened to review the author nominations list as a "first cut" in identifying potential chapter authors for this chapter. Using their knowledge of the Northeast's landscape and challenges, the CLA and CL used the list of national chapter topics that would be most relevant for the region. That topical list was associated with scientific expertise and a subset of the author list.

In the second phase, the CLA and CL used both the list of nominees as well as other scientists from around the region to build an author team that was representative of the Northeast's geography, institutional affiliation (federal agencies and academic and research institutions), depth of subject matter expertise, and knowledge of selected regional topics. Eleven authors were thus identified by December 2016, and the twelfth author was invited in April 2017 to better represent tribal knowledge in the chapter.

Lastly, the authors were contacted by the CL to determine their level of interest and willingness to serve as experts on the region's topics of water resources, agriculture and natural resources, oceans and marine ecosystems, coastal issues, health, and the built environment and urban issues.

On the due diligence of determining the region's topical areas of focus

The first two drafts of the Northeast chapter were structured around the themes of water resources, agriculture and natural resources, oceans and marine ecosystems, coastal issues, health, and the built environment and urban issues. During the USGCRP-sponsored Regional Engagement Workshop held in Boston on February 10, 2017, feedback was solicited from approximately 150 online participants (comprising transportation officials, coastal managers, urban planners, city managers, fisheries managers, forest managers, state officials, and others) around the Northeast and other parts of the United States, on both the content of these topical areas and important focal areas for the region. Additional inputs were solicited from other in-person meetings such as the ICNet workshop and American Association of Geographers meetings, both held in April 2017. All feedback was then compiled with the lessons learned from the USGCRP CLA-CL meeting in Washington, DC, also held in April 2017. On April 28, 2017, the author team met in Burlington, Vermont, and reworked the chapter's structure around the risk-based framing of interest to 1) changing seasonality, 2) coastal/ocean resources, 3) rural communities and livelihoods, 4) urban interconnectedness, and 5) adaptation.

Key Message 1

Changing Seasons Affect Rural Ecosystems, Environments, and Economies

The seasonality of the Northeast is central to the region's sense of place and is an important driver of rural economies. Less distinct seasons with milder winter and earlier spring conditions (*very high confidence*) are already altering ecosystems and environments (*high confidence*) in ways that adversely impact tourism (*very high confidence*), farming (*high confidence*), and forestry (*medium confidence*). The region's rural industries and livelihoods are at risk from further changes to forests, wildlife, snowpack, and streamflow (*likely*).

Description of evidence base

Multiple lines of evidence show that changes in seasonal temperature and precipitation cycles have been observed in the Northeast.[3,4,109,110,124,154,158] Projected increases in winter air temperatures under lower and higher scenarios (RCP4.5 and RCP8.5)[3,4] will result in shorter and milder cold seasons, a longer frost-free season,[3] and decreased regional snow cover and earlier snowmelt.[108,109,110,395,396,397] Observed seasonal changes to streamflows in response to increased winter precipitation, changes in snow hydrology,[112,138,139,140] and an earlier but prolonged transition into spring[68] are projected to continue.[105]

These changes are affecting a number of plant and animal species throughout the region, including earlier bloom times and leaf-out,[71,73,158] spawning,[164] migration,[84,166,398] and insect emergence,[74] as well as longer growing seasons,[72] delayed senescence, and enhanced leaf color change.[103] Milder winters will likely contribute to the range expansion of wildlife and insect species,[399] increase the size of certain herbivore populations[78] and their exposure to parasitism,[81,82] and increase the vulnerability of an array of plant and animal species to change.[66,103,143]

Warmer winters will likely contribute to declining yields for specialty crops[35] and fewer operational days for logging[88] and snow-dependent recreation.[115,116,118] Excess moisture is the leading cause of crop loss in the Northeast,[35] and the observed increase in precipitation amount, intensity, and persistence is projected to continue under both lower and higher scenarios.[3,4,124,125]

Major uncertainties

Warmer fall temperatures affect senescence, fruit ripening, migration, and hibernation, but are less well studied in the region[98] and must be considered alongside other climatic factors such as drought. Projections for summer rainfall in the Northeast are uncertain,[4] but evaporative demand for surface moisture is expected to increase with projected increases in summer temperatures.[3,4] Water use is highest during the warm season;[141,400] how much this will affect water availability for agricultural use depends on the frequency and intensity of drought during the growing season.[302]

Description of confidence and likelihood

There is *high confidence* that the combined effects of increasing winter and early-spring temperatures and increasing winter precipitation (*very high confidence*) are changing aquatic and terrestrial habitats and affecting the species adapted to them. The impact of changing seasonal temperature, moisture conditions, and habitats will vary geographically and impact interactions among species. It is *likely* that some will not adapt. There is *high confidence* that over the next century, some species will decline while other species introduced to the region thrive as conditions change. There is *high confidence* that increased precipitation in early spring will negatively impact farming, but the response of vegetation to future changes in seasonal temperature and moisture conditions depends on plant hardiness for *medium confidence* in the level of risk to specialty crops and forestry. A reduction in the length of the snow season by mid-century is *highly likely* under lower and higher scenarios, with *very high confidence* that the winter recreation industry will be negatively impacted by the end of the century under lower and higher scenarios (RCP4.5 and RCP8.5).

Key Message 2

Changing Coastal and Ocean Habitats, Ecosystem Services, and Livelihoods

The Northeast's coast and ocean support commerce, tourism, and recreation that are important to the region's economy and way of life. Warmer ocean temperatures, sea level rise, and ocean acidification (*high confidence*) threaten these services (*likely*). The adaptive capacity of marine ecosystems and coastal communities will influence ecological and socioeconomic outcomes as climate risks increase (*high confidence*).

Description of evidence base

Warming rates on the Northeast Shelf have been higher than experienced in other ocean regions,[39] and climate projections indicate that warming in this region will continue to exceed rates expected in other ocean regions.[48,49] Multiple lines of research have shown that changes in ocean temperatures and acidification have resulted in distribution,[7,8,10] productivity,[39,173,191,401] and phenology shifts[155,158,163,164,166] in marine populations. These shifts have impacted marine fisheries and prompted industry adaptations to changes.[155,176,200]

Research also shows that sea level rise has been[12,46,205,206] and will be higher in the Northeast with respect to the rest of the United States[12,249,250,251] due largely to vertical land movement,[207,208,209] varying atmospheric shifts and ocean dynamics,[210,211,212,213,215,252] and ice mass loss from the polar regions.[214] High tide flooding has increased[216,402] and will continue to increase,[403] and storm surges due to stronger and more frequent hurricanes[50,254,255] have been and will be amplified by sea level rise.[217,220,221,289] Climate-related coastal impacts on the landscape include greater potential for coastal flooding, erosion, overwash, barrier island breaching and disaggregation, and marsh conversion to open water,[12,216,223,226,256,257,258,259,263,279,404] which will directly affect the ability of ecosystems to sustain many of the services they provide. Changes to salt marshes in response to sea level rise have already been observed in some coastal settings in the region, although their impacts are site specific and variable.[265,266,267,268,269,270,271,405] Studies quantifying sea level rise impacts on other types of coastal settings (such as beaches) in the region are more limited; however, there is consensus on what impacts under higher rates of relative sea level rise might look like due to geologic history and modern analogs elsewhere (such as the Louisiana coast).[12,226,404] Although probabilistically low, worst-case sea level rise projections that account for ice sheet collapse[47,406] would result in sea level rise rates far beyond the rates at which natural systems are likely able to adapt,[274,275,280] affecting not only ecosystems function and services but also likely substantially changing the coastal landscape largely through inundation.[223]

Major uncertainties

Although work to value coastal and marine ecosystems services is still evolving,[6,41,281] changes to coastal ecosystem services will depend largely on the adaptability of the coastal landscape, direct hits from storms, and rate of sea level rise, which have identified uncertainties. Lower sea level rise rates are more probable, though the timing of ice sheet collapse[407] and the variability of ocean dynamics are still not well understood[210,211,215] and will dramatically affect the rate of rise.[47,406] It is also difficult to anticipate how humans will contend with changes along the coast[389] and how adjacent natural settings will respond. Furthermore, specific tipping points for many coastal ecosystems are still not well resolved[275,277,280] and vary due to site-specific conditions[224,274]

The Northeast Shelf is sensitive to ocean acidification, and many fisheries in the region are dependent on shell-forming organisms.[181,182,186] However, few studies that have investigated the impacts of ocean acidification on species biology and ecology used native populations from the region[182] or tested the effects at acidification levels expected over the next 20–40 years.[143] Moreover, there are limited studies that consider the effects of climate change in conjunction with multiple other stressors that affect marine populations.[39,40,178,408] Limited understanding of the adaptive capacity of species to environmental changes presents major uncertainties in ecosystem responses to climate change.[143,409] How humans will respond to changes in ecosystems is also not well known, yet these decisions will shape how marine industries and coastal communities are affected by climate change.[45]

Description of confidence and likelihood

Warming ocean temperatures (*high confidence*), acidification (*high confidence*), and sea level rise (*very high confidence*) will alter coastal and ocean ecosystems (*likely*) and threaten the ecosystems services provided by the coasts and oceans (*likely*) in the Northeast. There is *high confidence* that ocean temperatures have caused shifts in the distribution, productivity, and phenology of marine species and *very high confidence* that high tide flooding and storm surge impacts are being amplified by sea level rise. Because much will depend on how humans choose to address or adapt to these problems, and as there is considerable uncertainty over the extent to which many of these coastal systems will be able to adapt, there is *medium confidence* in the level of risk to traditions and livelihoods. It is *likely* that under higher scenarios, sea level rise will significantly alter the coastal landscape, and rising temperatures and acidification will affect marine populations and fisheries.

Key Message 3

Maintaining Urban Areas and Communities and Their Interconnectedness

The Northeast's urban centers and their interconnections are regional and national hubs for cultural and economic activity. Major negative impacts on critical infrastructure, urban economies, and nationally significant historic sites are already occurring and will become more common with a changing climate. (*High Confidence*)

Description of evidence base

The urban built environment and related supply and management systems are at increased risk of disruption from a variety of increasing climate risks. These risks emerge from accelerated sea level rise as well as increased frequency of coastal and estuarine flooding, intense precipitation events, urban heating and heat waves, and drought.

Coastal flooding can lead to adverse health consequences, loss of life, and damaged property and infrastructure.[368] Much of the region's major industries and cities are located along the coast, with 88% of the region's population and 68% of the regional gross domestic product.[260] High tide flooding is also increasingly problematic and costly.[47] Rising sea level and amplified storm events can increase the magnitude and geographic size of a coastal flood event. The frequency of dangerous coastal flooding in the Northeast would more than triple with 2 feet of sea level rise.[93] In Boston, the areal extent of a 1% (1 in 100 chance of occurring in any given year) flood is expected to increase multifold in many coastal neighborhoods.[295] However, there will likely be notable variability across coastal locations. Using the 2014 U.S. National Climate Assessment's Intermediate-High scenario for sea level rise (a global rise of 1.2 meters by 2100), the median number of flood events per year for the Northeast is projected to increase from 1 event per year experienced today to 5 events by 2030 and 25 events by 2045, with significant variation within the region.[410]

Intense precipitation events can lead to riverine and street-level flooding affecting urban environments. Over recent decades, the Northeast has experienced an increase of intense precipitation events, particularly in the spring and fall.[411] From 1958 to 2016, the number of heaviest 1% precipitation events (that is, an event that has a 1% chance of occurring in any given year) in the Northeast has increased by 55%.[58] A recent study suggests that this trend began rather abruptly after 1996, though uniformly across the region.[411]

Urban heating and heat waves threaten the health of the urban population and the integrity of the urban landscape. Due to the urban heat island effect, summer surface temperatures across Northeast cities were an average of 13°F to 16°F (7°C to 9°C) warmer than surrounding rural areas over a three-year period, 2003 to 2005.[412] This is of concern, as rising temperatures increase heat- and pollution-related mortality while also stressing energy demands across the urban environment.[413] However, the degree of urban heat island intensity varies across cities depending on local factors such as whether the city is coastal or inland.[414] Recent analysis of mortality in major cities of the Northeast suggests that the region could experience an additional 2,300 deaths per year by 2090 from extreme heat under RCP8.5 (compared to an estimated 970 deaths per year under the lower scenario, RCP4.5) compared to 1989–2000.[29] Another study that considered 1,692 cities around the world suggested that without mitigation, total economic costs associated with climate change could be 2.6 times higher due to the warmer temperatures in urban versus extra-urban environments.[415]

Changes in temperature and precipitation can have dramatic impacts on urban water supply available for municipal and industrial uses. Under a higher scenario (RCP8.5), the Northeast is projected to experience cumulative losses of $730 million (discounted at 3% in 2015 dollars) due to water supply shortfalls for the period 2015 to 2099.[29] Under a lower scenario (RCP4.5), the Northeast is projected to sustain losses of $510 million (discounted at 3% in 2015 dollars).[29] The losses are largely projected for the more southern and coastal areas in the region.

Major uncertainties

Projecting changes in urban pollution and air quality under a changing climate is challenging given the associated complex chemistry and underlying factors that influence it. For example, fine particulates ($PM_{2.5}$; that is, particles with a diameter of or less than 2.5 micrometers) are affected by cloud processes and precipitation, amongst other meteorological processes, leading to considerable uncertainty in the geographic distribution and overall trend in both modeling analysis and the literature.[29] Land use can also play an unexpected role, such as planting trees as a mitigation option that may lead to increases in volatile organic compounds (VOCs), which, in a VOC-limited environment that can exist in some urban areas such as New York City, may increase ozone concentrations (however, it is noted that most of the Northeast region is limited by the availability of nitrogen oxides).[327]

Interdependencies among infrastructure sectors can lead to unexpected and amplified consequences in response to extreme weather events. However, it is unclear how society may choose to invest in the built environment, possibly strengthening urban infrastructure to plausible future conditions.

Description of confidence and likelihood

There is *high confidence* that weather-related impacts on urban centers already experienced today will become more common under a changing climate. For the Northeast, sea level rise is projected to occur at a faster rate than the global average, potentially increasing the impact of moderate and severe coastal flooding.[47]

By the end of the century and under a higher scenario (RCP8.5), Coupled Model Intercomparison Project Phase 5 (CMIP5) models suggest that annual average temperatures will increase by more than 9°F (16°C) for much of the region (2071–2100 compared to 1976–2005), while precipitation is projected to increase, particularly during winter and spring.[50]

Extreme events that impact urban environments have been observed to increase over much of the United States and are projected to continue to intensify. There is *high confidence* that heavy precipitation events have increased in intensity and frequency since 1901, with the largest increase in the Northeast, a trend projected to continue.[50] There is *very high confidence* that extreme heat events are increasing across most regions worldwide, a trend very likely to continue.[50] Extreme precipitation from tropical cyclones has not demonstrated a clear observed trend but is expected to increase in the future.[50,253] Research has suggested that the number of tropical cyclones will overall increase with future warming.[416] However, this finding is contradicted by results using a high-resolution dynamical downscaling study under a lower scenario (RCP4.5), which suggests overall reduction in frequency of tropical cyclones but an increase in the occurrence of storms of Saffir–Simpson categories 4 and 5.[50]

Key Message 4

Threats to Human Health

Changing climate threatens the health and well-being of people in the Northeast through more extreme weather, warmer temperatures, degradation of air and water quality, and sea level rise (*very high confidence*). These environmental changes are expected to lead to health-related impacts and costs, including additional deaths, emergency room visits and hospitalizations, and a lower quality of life (*very high confidence*). Health impacts are expected to vary by location, age, current health, and other characteristics of individuals and communities (*very high confidence*).

Description of evidence base

Extreme storms and temperatures, overall warmer temperatures, degradation of air and water quality, and sea level rise are all associated with adverse health outcomes from heat,[20,21,22,23,305,306,307] poor air quality,[324,325,326] disease-transmitting vectors,[67,333,334] contaminated food and water,[322,340,341,344] harmful algal blooms,[335] and traumatic stress or health service disruption.[17,349] The underlying susceptibility of populations determines whether or not there are health impacts from an exposure and the severity of such impacts.[307,308]

Major uncertainties

Uncertainty remains in projections of the magnitude of future changes in particulate matter, humidity, and wildfires and how these changes may influence health risks. For example, health effects of future extreme heat may be exacerbated by future changes in absolute or relative humidity.

Health impacts are ultimately determined by not just the environmental hazard but also the amount of exposure, size and underlying susceptibility of the exposed population, and other factors such as health insurance coverage and access to timely healthcare services. In projecting future health risks, researchers acknowledge these challenges and use different analytic approaches to address this uncertainty or note it as a limitation.[23,28,326]

In addition, there is a paucity of literature that considers the joint or cumulative impacts on health of multiple climatic hazards. Additional areas where the literature base is limited include specific health impacts related to different types of climate-related migration, the impact of climatic factors on mental health, and the specific timing and geographic range of shifting disease-carrying vectors.

Description of confidence and likelihood

There is *very high confidence* that extreme weather, warmer temperatures, degradation of air and water quality, and sea level rise threaten the health and well-being of people in the Northeast. There is *very high confidence* that these climate-related environmental changes will lead to additional adverse health-related impacts and costs, including premature deaths, more emergency department visits and hospitalizations, and lower quality of life. There is *very high confidence* that climate-related health impacts will vary by location, age, current health, and other characteristics of individuals and communities.

Key Message 5

Adaptation to Climate Change Is Underway

Communities in the Northeast are proactively planning (*high confidence*) and implementing (*medium confidence*) actions to reduce risks posed by climate change. Using decision support tools to develop and apply adaptation strategies informs both the value of adopting solutions and the remaining challenges (*high confidence*). Experience since the last assessment provides a foundation to advance future adaptation efforts (*high confidence*).

Description of evidence base

Reports on climate adaptation and resilience planning have been published by city, state, and tribal governments and by regional and federal agencies in the Northeast. Examples include the Interstate Commission on the Potomac River Basin (for the Washington, DC, metropolitan area),[304] Boston,[295] the Port Authority of New York and New Jersey,[357] the St. Regis Mohawk Tribe,[360] the U.S. Army Corps of Engineers,[368] the State of Maine,[381] and southeastern Connecticut.[417] Structured decision-making is being applied to design management plans, determine research needs, and allocate resources[365] to preserve habitat and resources throughout the region.[151,366,367]

Major uncertainties

The percentage of communities in the Northeast that are planning for climate adaptation and resilience and the percentage of those using decision support tools are not known. More case studies would be needed to evaluate the effectiveness of adaptation actions.

Description of confidence and likelihood

There is *high confidence* that there are communities in the Northeast undertaking planning efforts to reduce risks posed from climate change and *medium confidence* that they are implementing climate adaptation. There is *high confidence* that decision support tools are informative and *medium confidence* that these communities are using decision support tools to find solutions for adaptation that are workable. There is *high confidence* that early adoption is occurring in some communities and that this provides a foundation for future efforts. This Key Message does not address trends into the future, and therefore likelihood is not applicable.

References

1. Rustad, L., J. Campbell, J.S. Dukes, T. Huntington, K.F. Lambert, J. Mohan, and N. Rodenhouse, 2012: Changing Climate, Changing Forests: The Impacts of Climate Change on Forests of the Northeastern United States and Eastern Canada. Gen. Tech. Rep. NRS-99. USDA, Forest Service, Northern Research Station, Newtown Square, PA, 48 pp. http://dx.doi.org/10.2737/NRS-GTR-99

2. Hoerling, M., J. Eischeid, J. Perlwitz, X.-W. Quan, K. Wolter, and L. Cheng, 2016: Characterizing recent trends in U.S. heavy precipitation. *Journal of Climate*, **29** (7), 2313-2332. http://dx.doi.org/10.1175/jcli-d-15-0441.1

3. Thibeault, J.M. and A. Seth, 2014: Changing climate extremes in the Northeast United States: Observations and projections from CMIP5. *Climatic Change*, **127** (2), 273-287. http://dx.doi.org/10.1007/s10584-014-1257-2

4. Lynch, C., A. Seth, and J. Thibeault, 2016: Recent and projected annual cycles of temperature and precipitation in the northeast United States from CMIP5. *Journal of Climate*, **29** (1), 347-365. http://dx.doi.org/10.1175/jcli-d-14-00781.1

5. National Marine Fisheries Service, 2016: Fisheries of the United States 2015. Current Fishery Statistics No. 2015, Lowther, A. and M. Liddel, Eds. National Oceanic and Atmospheric Administration, Silver Spring, MD, 135 pp. https://www.st.nmfs.noaa.gov/Assets/commercial/fus/fus15/documents/FUS2015.pdf

6. Liquete, C., C. Piroddi, E.G. Drakou, L. Gurney, S. Katsanevakis, A. Charef, and B. Egoh, 2013: Current status and future prospects for the assessment of marine and coastal ecosystem services: A systematic review. PLOS ONE, **8** (7), e67737. http://dx.doi.org/10.1371/journal.pone.0067737

7. Nye, J.A., J.S. Link, J.A. Hare, and W.J. Overholtz, 2009: Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. *Marine Ecology Progress Series*, **393**, 111-129. http://dx.doi.org/10.3354/meps08220

8. Pinsky, M.L., B. Worm, M.J. Fogarty, J.L. Sarmiento, and S.A. Levin, 2013: Marine taxa track local climate velocities. *Science*, **341** (6151), 1239-1242. http://dx.doi.org/10.1126/science.1239352

9. Bell, R.J., D.E. Richardson, J.A. Hare, P.D. Lynch, and P.S. Fratantoni, 2015: Disentangling the effects of climate, abundance, and size on the distribution of marine fish: An example based on four stocks from the Northeast US shelf. *ICES Journal of Marine Science*, **72** (5), 1311-1322. http://dx.doi.org/10.1093/icesjms/fsu217

10. Kleisner, K.M., M.J. Fogarty, S. McGee, A. Barnett, P. Fratantoni, J. Greene, J.A. Hare, S.M. Lucey, C. McGuire, J. Odell, V.S. Saba, L. Smith, K.J. Weaver, and M.L. Pinsky, 2016: The effects of sub-regional climate velocity on the distribution and spatial extent of marine species assemblages. PLOS ONE, **11** (2), e0149220. http://dx.doi.org/10.1371/journal.pone.0149220

11. Miller, A.S., G.R. Shepherd, and P.S. Fratantoni, 2016: Offshore habitat preference of overwintering juvenile and adult black sea bass, *Centropristis striata*, and the relationship to year-class success. PLOS ONE, **11** (1), e0147627. http://dx.doi.org/10.1371/journal.pone.0147627

12. Miller, K.G., R.E. Kopp, B.P. Horton, J.V. Browning, and A.C. Kemp, 2013: A geological perspective on sea-level rise and its impacts along the U.S. mid-Atlantic coast. *Earth's Future*, **1** (1), 3-18. http://dx.doi.org/10.1002/2013EF000135

13. Lentz, E.E., E.R. Thieler, N.G. Plant, S.R. Stippa, R.M. Horton, and D.B. Gesch, 2016: Evaluation of dynamic coastal response to sea-level rise modifies inundation likelihood. *Nature Climate Change*, **6** (7), 696-700. http://dx.doi.org/10.1038/nclimate2957

14. Reed, A.J., M.E. Mann, K.A. Emanuel, N. Lin, B.P. Horton, A.C. Kemp, and J.P. Donnelly, 2015: Increased threat of tropical cyclones and coastal flooding to New York City during the anthropogenic era. *Proceedings of the National Academy of Sciences of the United States of America*, **112** (41), 12610-12615. http://dx.doi.org/10.1073/pnas.1513127112

15. Rosenzweig, C. and W. Solecki, 2015: New York City Panel on Climate Change 2015 Report Introduction. *Annals of the New York Academy of Sciences*, **1336** (1), 3-5. http://dx.doi.org/10.1111/nyas.12625

16. Kopp, R.E., A. Broccoli, B.P. Horton, D. Kreeger, R. Leichenko, J.A. Miller, J.K. Miller, P. Orton, A. Parris, D.A. Robinson, C.P. Weaver, M. Campo, M.B. Kaplan, M.K. Buchanan, J. Herb, L. Auermuller, and C.J. Andrews, 2016: Assessing New Jersey's Exposure to Sea-Level Rise and Coastal Storms: Report of the New Jersey Climate Adaptation Alliance Science and Technical Advisory Panel. New Jersey Climate Adaptation Alliance, New Brunswick, NJ, 34 pp. http://dx.doi.org/10.7282/T3ZP48CF

17. Horton, R., C. Rosenzweig, W. Solecki, D. Bader, and L. Sohl, 2016: Climate science for decision-making in the New York metropolitan region. *Climate in Context: Science and Society Partnering for Adaptation*. Parris, A.S., G.M. Garfin, K. Dow, R. Meyer, and S.L. Close, Eds. Wiley, New York, 51-72.

18. Runkle, J., K.E. Kunkel, R. Frankson, and B.C. Stewart, 2017: State Climate Summaries: West Virginia. NOAA Technical Report NESDIS 149-WV. NOAA National Centers for Environmental Information, Asheville, NC, 4 pp. https://statesummaries.ncics.org/wv

19. Runkle, J., K.E. Kunkel, D. Easterling, B.C. Stewart, S. Champion, L. Stevens, R. Frankson, and W. Sweet, 2017: State Climate Summaries: Rhode Island. NOAA Technical Report NESDIS 149-RI. NOAA National Centers for Environmental Information, Asheville, NC, 4 pp. https://statesummaries.ncics.org/ri

20. Bobb, J.F., R.D. Peng, M.L. Bell, and F. Dominici, 2014: Heat-related mortality and adaptation to heat in the United States. *Environmental Health Perspectives*, **122** (8), 811-816. http://dx.doi.org/10.1289/ehp.1307392

21. Petkova, E.P., A. Gasparrini, and P.L. Kinney, 2014: Heat and mortality in New York City since the beginning of the 20th century. *Epidemiology*, **25** (4), 554-560. http://dx.doi.org/10.1097/ede.0000000000000123

22. Wang, Y., J.F. Bobb, B. Papi, Y. Wang, A. Kosheleva, Q. Di, J.D. Schwartz, and F. Dominici, 2016: Heat stroke admissions during heat waves in 1,916 US counties for the period from 1999 to 2010 and their effect modifiers. *Environmental Health*, **15** (1), 83. http://dx.doi.org/10.1186/s12940-016-0167-3

23. Petkova, E.P., J.K. Vink, R.M. Horton, A. Gasparrini, D.A. Bader, J.D. Francis, and P.L. Kinney, 2017: Towards more comprehensive projections of urban heat-related mortality: Estimates for New York City under multiple population, adaptation, and climate scenarios. *Environmental Health Perspectives*, **125** (1), 47-55. http://dx.doi.org/10.1289/EHP166

24. Matte, T.D., K. Lane, and K. Ito, 2016: Excess mortality attributable to extreme heat in New York City, 1997-2013. *Health Security*, **14** (2), 64-70. http://dx.doi.org/10.1089/hs.2015.0059

25. Petkova, E.P., R.M. Horton, D.A. Bader, and P.L. Kinney, 2013: Projected heat-related mortality in the U.S. urban northeast. *International Journal of Environmental Research and Public Health*, **10** (12), 6734-6747. http://dx.doi.org/10.3390/ijerph10126734

26. Kingsley, S.L., M.N. Eliot, J. Gold, R.R. Vanderslice, and G.A. Wellenius, 2016: Current and projected heat-related morbidity and mortality in Rhode Island. *Environmental Health Perspectives*, **124** (4), 460-467. http://dx.doi.org/10.1289/ehp.1408826

27. Weinberger, K.R., L. Haykin, M.N. Eliot, J.D. Schwartz, A. Gasparrini, and G.A. Wellenius, 2017: Projected temperature-related deaths in ten large U.S. metropolitan areas under different climate change scenarios. *Environment International*, **107**, 196-204. http://dx.doi.org/10.1016/j.envint.2017.07.006

28. Schwartz, J.D., M. Lee, P.L. Kinney, S. Yang, D. Mills, M. Sarofim, R. Jones, R. Streeter, A. St. Juliana, J. Peers, and R.M. Horton, 2015: Projections of temperature-attributable premature deaths in 209 U.S. cities using a cluster-based Poisson approach. *Environmental Health*, **14**. http://dx.doi.org/10.1186/s12940-015-0071-2

29. EPA, 2017: Multi-model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. EPA 430-R-17-001. U.S. Environmental Protection Agency (EPA), Washington, DC, 271 pp. https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=335095

30. New Jersey Resilient Coastal Communities Initiative, 2018: Getting to Resilience: A Community Planning Evaluation Tool [web tool]. http://www.prepareyourcommunitynj.org/

31. New York Climate Change Science Clearinghouse, 2018: [web site]. https://nyclimatescience.org/

32. Beach SAMP, 2018: STORMTOOLS [web tool]. Rhode Island Shoreline Change Special Area Management Plan (Beach SAMP), Kingston, RI. http://www.beachsamp.org/stormtools/

33. EPA, 2017: Climate Change: Resilience and Adaptation in New England (RAINE). U.S. Environmental Protection Agency (EPA), Washington, DC, accessed September 21, 2017. https://www.epa.gov/raine

34. CDC, 2015: CDC's Building Resilience Against Climate Effects (BRACE) Framework [web site]. Centers for Disease Control and Prevention (CDC), Atlanta, GA. https://www.cdc.gov/climateandhealth/BRACE.htm

35. Wolfe, D.W., A.T. DeGaetano, G.M. Peck, M. Carey, L.H. Ziska, J. Lea-Cox, A.R. Kemanian, M.P. Hoffmann, and D.Y. Hollinger, 2018: Unique challenges and opportunities for northeastern US crop production in a changing climate. *Climatic Change*, **146** (1-2), 231-245. http://dx.doi.org/10.1007/s10584-017-2109-7

36. Karmalkar, A.V. and R.S. Bradley, 2017: Consequences of global warming of 1.5 °C and 2 °C for regional temperature and precipitation changes in the contiguous United States. PLOS ONE, **12** (1), e0168697. http://dx.doi.org/10.1371/journal.pone.0168697

37. Hughes, J.E., L.A. Deegan, J.C. Wyda, M.J. Weaver, and A. Wright, 2002: The effects of eelgrass habitat loss on estuarine fish communities of southern New England. *Estuaries and Coasts*, **25** (2), 235-249. http://dx.doi.org/10.1007/BF02691311

38. Beck, M.W., K.L. Heck, K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshino, T.J. Minello, R.J. Orth, P.F. Sheridan, and M.P. Weinstein, 2001: The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: A better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *BioScience*, **51** (8), 633-641. http://dx.doi.org/10.1641/0006-3568(2001)051[0633:TICAMO]2.0.CO;2

39. Pershing, A.J., M.A. Alexander, C.M. Hernandez, L.A. Kerr, A. Le Bris, K.E. Mills, J.A. Nye, N.R. Record, H.A. Scannell, J.D. Scott, G.D. Sherwood, and A.C. Thomas, 2015: Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. *Science*, **350** (6262), 809-812. http://dx.doi.org/10.1126/science.aac9819

40. Le Bris, A., K.E. Mills, R.A. Wahle, Y. Chen, M.A. Alexander, A.J. Allyn, J.G. Schuetz, J.D. Scott, and A.J. Pershing, 2018: Climate vulnerability and resilience in the most valuable North American fishery. *Proceedings of the National Academy of Sciences of the United States of America*, **115** (8), 1831-1836. http://dx.doi.org/10.1073/pnas.1711122115

41. Barbier, E.B., S.D. Hacker, C. Kennedy, E.W. Koch, A.C. Stier, and B.R. Silliman, 2011: The value of estuarine and coastal ecosystem services. *Ecological Monographs*, **81** (2), 169-193. http://dx.doi.org/10.1890/10-1510.1

42. Selden, R.L., R.D. Batt, V.S. Saba, and M.L. Pinsky, 2017: Diversity in thermal affinity among key piscivores buffers impacts of ocean warming on predator–prey interactions. *Global Change Biology*, **24** (1), 117-131. http://dx.doi.org/10.1111/gcb.13838

43. Nordstrom, K.F., 2014: Living with shore protection structures: A review. *Estuarine, Coastal and Shelf Science*, **150**, 11-23. http://dx.doi.org/10.1016/j.ecss.2013.11.003

44. Jacobs, J.M., L.R. Cattaneo, W. Sweet, and T. Mansfield, 2018: Recent and future outlooks for nuisance flooding impacts on roadways on the US East Coast. *Transportation Research Record*. http://dx.doi.org/10.1177/0361198118756366

45. Colburn, L.L., M. Jepson, C. Weng, T. Seara, J. Weiss, and J.A. Hare, 2016: Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. *Marine Policy*, **74**, 323-333. http://dx.doi.org/10.1016/j.marpol.2016.04.030

46. Sallenger, A.H., K.S. Doran, and P.A. Howd, 2012: Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change*, **2**, 884-888. http://dx.doi.org/10.1038/nclimate1597

47. Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas, 2017: Global and Regional Sea Level Rise Scenarios for the United States. NOAA Tech. Rep. NOS CO-OPS 083. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 75 pp. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

48. Saba, V.S., S.M. Griffies, W.G. Anderson, M. Winton, M.A. Alexander, T.L. Delworth, J.A. Hare, M.J. Harrison, A. Rosati, G.A. Vecchi, and R. Zhang, 2016: Enhanced warming of the northwest Atlantic Ocean under climate change. *Journal of Geophysical Research Oceans*, **121** (1), 118-132. http://dx.doi.org/10.1002/2015JC011346

49. Alexander, M.A., J.D. Scott, K. Friedland, K.E. Mills, J.A. Nye, A.J. Pershing, and A.C. Thomas, 2018: Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. *Elementa: Science of the Anthropocene*, **6** (1), Art. 9. http://dx.doi.org/10.1525/elementa.191

50. USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, 470 pp. http://dx.doi.org/10.7930/J0J964J6

51. Leichenko, R.M. and W.D. Solecki, 2013: Climate change in suburbs: An exploration of key impacts and vulnerabilities. *Urban Climate*, **6**, 82-97. http://dx.doi.org/10.1016/j.uclim.2013.09.001

52. Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, and P. Grabhorn, Eds., 2011: *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical report*. NYSERDA Report 11-18. New York State Energy Research and Development Authority (NYSERDA), Albany, NY, 149 pp. https://www.nyserda.ny.gov/climaid

53. Nelson, A.C. and R.E. Lang, 2011: *Megapolitan America: A New Vision for Understanding America's Metropolitan Geography*. Routledge, London and New York, 312 pp.

54. Deller, S.C., D. Lamie, and M. Stickel, 2017: Local foods systems and community economic development. *Community Development*, **48** (5), 612-638. http://dx.doi.org/10.1080/15575330.2017.1373136

55. Wu, J., B.A. Weber, and M.D. Partridge, 2017: Rural-urban interdependence: A framework integrating regional, urban, and environmental economic insights. *American Journal of Agricultural Economics*, **99** (2), 464-480. http://dx.doi.org/10.1093/ajae/aaw093

56. Black, R., D. Kniveton, and K. Schmidt-Verkerk, 2013: Migration and climate change: Toward an integrated assessment of sensitivity. *Disentangling Migration and Climate Change: Methodologies, Political Discourses and Human Rights*. Faist, T. and J. Schade, Eds. Springer Netherlands, Dordrecht, 29-53. http://dx.doi.org/10.1007/978-94-007-6208-4_2

57. U.S. Census Bureau, 2018: Table A-2. Annual Inmigration, Outmigration, Net Migration and Movers from Abroad for Regions: 1981-2017, CPS Historical Migration/Geographic Mobility Tables. U.S. Census Bureau, Washington, DC. https://www.census.gov/data/tables/time-series/demo/geographic-mobility/historic.html

58. Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017: Precipitation change in the United States. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 207-230. http://dx.doi.org/10.7930/J0H993CC

59. Rosenzweig, C., W.D. Solecki, P. Romeo-Lankao, S. Mehrotra, S. Dhakal, and S.A. Ibrahim, Eds., 2018: *Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network*. Cambridge University Press, 350 pp.

60. Azevedo de Almeida, B. and A. Mostafavi, 2016: Resilience of infrastructure systems to sea-level rise in coastal areas: Impacts, adaptation measures, and implementation challenges. *Sustainability*, **8** (11), 1115. http://dx.doi.org/10.3390/su8111115

61. Artigas, F., J.M. Loh, J.Y. Shin, J. Grzyb, and Y. Yao, 2017: Baseline and distribution of organic pollutants and heavy metals in tidal creek sediments after Hurricane Sandy in the Meadowlands of New Jersey. *Environmental Earth Sciences*, **76** (7), 293. http://dx.doi.org/10.1007/s12665-017-6604-y

62. Mandigo, A.C., D.J. DiScenza, A.R. Keimowitz, and N. Fitzgerald, 2016: Chemical contamination of soils in the New York City area following Hurricane Sandy. *Environmental Geochemistry and Health*, **38** (5), 1115-1124. http://dx.doi.org/10.1007/s10653-015-9776-y

63. Personna, Y.R., X. Geng, F. Saleh, Z. Shu, N. Jackson, M.P. Weinstein, and M.C. Boufadel, 2015: Monitoring changes in salinity and metal concentrations in New Jersey (USA) coastal ecosystems Post-Hurricane Sandy. *Environmental Earth Sciences*, **73** (3), 1169-1177. http://dx.doi.org/10.1007/s12665-014-3539-4

64. Outdoor Industry Association, 2017: The Outdoor Recreation Economy. Outdoor Industry Association, Boulder, CO, 19 pp. https://outdoorindustry.org/wp-content/uploads/2017/04/OIA_RecEconomy_FINAL_Single.pdf

65. Lopez, R., N. Plesha, B. Campbell, and C. Laughton, 2015: Northeast Economic Engine: Agriculture, Forest Products and Commercial Fishing. Farm Credit East, Enfield, CT, 25 pp. http://www.are.uconn.edu/index_42_1981703122.pdf

66. Staudinger, M.D., T.L. Morelli, and A.M. Bryan, 2015: Integrating Climate Change into Northeast and Midwest State Wildlife Action Plans. Northeast Climate Science Center, Amherst, MA, 201 pp. http://necsc.umass.edu/biblio/integrating-climate-change-northeast-and-midwest-state-wildlife-action-plans

67. Monaghan, A.J., S.M. Moore, K.M. Sampson, C.B. Beard, and R.J. Eisen, 2015: Climate change influences on the annual onset of Lyme disease in the United States. *Ticks and Tick-Borne Diseases*, **6** (5), 615-622. http://dx.doi.org/10.1016/j.ttbdis.2015.05.005

68. Contosta, A.R., A. Adolph, D. Burchsted, E. Burakowski, M. Green, D. Guerra, M. Albert, J. Dibb, M. Martin, W.H. McDowell, M. Routhier, C. Wake, R. Whitaker, and W. Wollheim, 2017: A longer vernal window: The role of winter coldness and snowpack in driving spring transitions and lags. *Global Change Biology*, **23** (4), 1610-1625. http://dx.doi.org/10.1111/gcb.13517

69. Polgar, C.A. and R.B. Primack, 2011: Leaf-out phenology of temperate woody plants: From trees to ecosystems. *New Phytologist*, **191** (4), 926-941. http://dx.doi.org/10.1111/j.1469-8137.2011.03803.x

70. Swanston, C., L.A. Brandt, M.K. Janowiak, S.D. Handler, P. Butler-Leopold, L. Iverson, F.R. Thompson III, T.A. Ontl, and P.D. Shannon, 2018: Vulnerability of forests of the Midwest and Northeast United States to climate change. *Climatic Change*, **146** (1), 103-116. http://dx.doi.org/10.1007/s10584-017-2065-2

71. Ault, T.R., M.D. Schwartz, R. Zurita-Milla, J.F. Weltzin, and J.L. Betancourt, 2015: Trends and natural variability of spring onset in the coterminous United States as evaluated by a new gridded dataset of spring indices. *Journal of Climate*, **28** (21), 8363-8378. http://dx.doi.org/10.1175/jcli-d-14-00736.1

72. Keenan, T.F., J. Gray, M.A. Friedl, M. Toomey, G. Bohrer, D.Y. Hollinger, J.W. Munger, J. O/'Keefe, H.P. Schmid, I.S. Wing, B. Yang, and A.D. Richardson, 2014: Net carbon uptake has increased through warming-induced changes in temperate forest phenology. *Nature Climate Change*, **4** (7), 598-604. http://dx.doi.org/10.1038/nclimate2253

73. Gu, L., P.J. Hanson, W.M. Post, D.P. Kaiser, B. Yang, R. Nemani, S.G. Pallardy, and T. Meyers, 2008: The 2007 eastern US spring freeze: Increased cold damage in a warming world? *BioScience*, **58** (3), 253-262. http://dx.doi.org/10.1641/B580311

74. Menzel, A., T.H. Sparks, N. Estrella, E. Koch, A. Aasa, R. Ahas, K. Alm-Kübler, P. Bissolli, O.G. Braslavská, A. Briede, F.M. Chmielewski, Z. Crepinsek, Y. Curnel, Å. Dahl, C. Defila, A. Donnelly, Y. Filella, K. Jatczak, F. Måge, A. Mestre, Ø. Nordli, J. Peñuelas, P. Pirinen, V. Remišvá, H. Scheifinger, M. Striz, A. Susnik, A.J.H. Van Vliet, F.-E. Wielgolaski, S. Zach, and A.N.A. Zust, 2006: European phenological response to climate change matches the warming pattern. *Global Change Biology*, **12** (10), 1969-1976. http://dx.doi.org/10.1111/j.1365-2486.2006.01193.x

75. Paradis, A., J. Elkinton, K. Hayhoe, and J. Buonaccorsi, 2008: Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. *Mitigation and Adaptation Strategies for Global Change*, **13** (5-6), 541-554. http://dx.doi.org/10.1007/s11027-007-9127-0

76. DeSantis, R.D., W.K. Moser, D.D. Gormanson, M.G. Bartlett, and B. Vermunt, 2013: Effects of climate on emerald ash borer mortality and the potential for ash survival in North America. *Agricultural and Forest Meteorology*, **178–179**, 120-128. http://dx.doi.org/10.1016/j.agrformet.2013.04.015

77. Weed, A.S., M.P. Ayres, A.M. Liebhold, and R.F. Billings, 2017: Spatio-temporal dynamics of a tree-killing beetle and its predator. *Ecography*, **40** (1), 221-234. http://dx.doi.org/10.1111/ecog.02046

78. Brandt, L.A., P.R. Butler, S.D. Handler, M.K. Janowiak, P.D. Shannon, and C.W. Swanston, 2017: Integrating science and management to assess forest ecosystem vulnerability to climate change. *Journal of Forestry*, **115** (3), 212-221. http://dx.doi.org/10.5849/jof.15-147

79. StateFarm, 2017: Chances of Hitting a Deer in My State [web site]. StateFarm, Bloomington, IL, last modified October 2. https://newsroom.statefarm.com/deer-collision-damage-claim-costs-up/

80. Nosakhare, O.K., I.T. Aighewi, A.Y. Chi, A.B. Ishaque, and G. Mbamalu, 2012: Land use–land cover changes in the lower eastern shore watersheds and coastal bays of Maryland: 1986–2006. *Journal of Coastal Research*, **28** (1A), 54-62. http://dx.doi.org/10.2112/jcoastres-d-09-00074.1

81. Rempel, R.S., 2011: Effects of climate change on moose populations: Exploring the response horizon through biometric and systems models. *Ecological Modelling*, **222** (18), 3355-3365. http://dx.doi.org/10.1016/j.ecolmodel.2011.07.012

82. Rodenhouse, N.L., L.M. Christenson, D. Parry, and L.E. Green, 2009: Climate change effects on native fauna of northeastern forests. *Canadian Journal of Forest Research*, **39** (2), 249-263. http://dx.doi.org/10.1139/X08-160

83. New Hampshire Fish and Game, 2017: Moose research: What's in store for New Hampshire's moose? New Hampshire Fish and Game, Concord, NH. http://www.wildlife.state.nh.us/wildlife/moose-study.html

84. Lehikoinen, E.S.A., T.H. Sparks, and M. Zalakevicius, 2004: Arrival and departure dates. *Advances in Ecological Research*. Academic Press, 1-31. http://dx.doi.org/10.1016/S0065-2504(04)35001-4

85. Ralston, J., D.I. King, W.V. DeLuca, G.J. Niemi, M.J. Glennon, J.C. Scarl, and J.D. Lambert, 2015: Analysis of combined data sets yields trend estimates for vulnerable spruce-fir birds in northern United States. *Biological Conservation*, **187**, 270-278. http://dx.doi.org/10.1016/j.biocon.2015.04.029

86. Janowiak, M.K., A.W. D'Amato, C.W. Swanston, L. Iverson, F. Thompson III, W. Dijak, S. Matthews, M. Peters, A. Prasad, J.S. Fraser, L.A. Brandt, P.R. Butler, S.D. Handler, P.D. Shannon, D. Burbank, J. Campbell, C. Cogbill, M.J. Duveneck, M. Emery, N. Fisichelli, J. Foster, J. Hushaw, L. Kenefic, A. Mahaffey, T.L. Morelli, N. Reo, P. Schaberg, K.R. Simmons, A. Weiskittel, S. Wilmot, D. Hollinger, E. Lane, L. Rustad, and P. Templer, 2018: New England and New York Forest Ecosystem Vulnerability Assessment and Synthesis. Gen. Tech. Rep. NRS-173. U.S. Department of Agriculture, Forest Service, Newtown Square, PA, 234 pp. https://www.fs.usda.gov/treesearch/pubs/55635

87. Janowiak, M.K., J. Nett, E. Johnson, N. Walker, S. Handler, and C. Swanston, 2018: Climate Change and Adaptation: New England and Northern New York Forests [story map]. USDA Forest Service, Newtown Square, PA. https://usfs.maps.arcgis.com/apps/MapSeries/index.html?appid=a4babe8e2fe849739171e6824930459e

88. Jantarasami, L.C., J.J. Lawler, and C.W. Thomas, 2010: Institutional barriers to climate change adaptation in US national parks and forests. *Ecology and Society*, **15** (4), 33. http://www.ecologyandsociety.org/vol15/iss4/art33/

89. Matthews, S.N. and L.R. Iverson, 2017: Managing for delicious ecosystem service under climate change: Can United States sugar maple (*Acer saccharum*) syrup production be maintained in a warming climate? *International Journal of Biodiversity Science, Ecosystem Services & Management*, **13** (2), 40-52. http://dx.doi.org/10.1080/21513732.2017.1285815

90. Skinner, C.B., A.T. DeGaetano, and B.F. Chabot, 2010: Implications of twenty-first century climate change on Northeastern United States maple syrup production: Impacts and adaptations. *Climatic Change*, **100** (3), 685-702. http://dx.doi.org/10.1007/s10584-009-9685-0

91. Duchesne, L. and D. Houle, 2014: Interannual and spatial variability of maple syrup yield as related to climatic factors. *PeerJ*, **2**, e428. http://dx.doi.org/10.7717/peerj.428

92. Oswald, E.M., J. Pontius, S.A. Rayback, P.G. Schaberg, S.H. Wilmot, and L.-A. Dupigny-Giroux, 2018: The complex relationship between climate and sugar maple health: Climate change implications in Vermont for a key northern hardwood species. *Forest Ecology and Management*, **422**, 303-312. http://dx.doi.org/10.1016/j.foreco.2018.04.014

93. Melillo, J.M., T.C. Richmond, and G.W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, Washington, DC, 841 pp. http://dx.doi.org/10.7930/J0Z31WJ2

94. Rapp, J., M. Duveneck, and J. Thompson, 2016: (Re)expansion of the maple syrup industry in New England: Projecting where the taps will be in a changing environment. In *Harvard Forest Symposium* 2016, Petersham, MA. Harvard Forest. http://harvardforest2.fas.harvard.edu/asp/hf/php/symposium/symposium_abstract_view.php?id=3752

95. Rapp, J., S. Ahmed, D. Lutz, R. Huish, B. Dufour, T.L. Morelli, and K. Stinson, 2017: Maple syrup in a changing climate. In *Northeast Climate Science Center's Regional Science Meeting: Incorporating Climate Science in the Management of Natural and Cultural Resources in the Midwest and Northeast*, Amherst, MA. Northeast Climate Science Center. http://necsc.umass.edu/ne-csc-regional-science-meeting-2017

96. Kimmerer, R. and N. Patterson, 2016: Annual Report. Center for Native Peoples and the Environment, Syracuse, NY, 22 pp. http://www.esf.edu/nativepeoples/documents/CNPE2016Report.pdf

97. Norton-Smith, K., K. Lynn, K. Chief, K. Cozzetto, J. Donatuto, M.H. Redsteer, L.E. Kruger, J. Maldonado, C. Viles, and K.P. Whyte, 2016: Climate Change and Indigenous Peoples: A Synthesis of Current Impacts and Experiences. Gen. Tech. Rep. PNW-GTR-944. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 136 pp. https://www.fs.usda.gov/treesearch/pubs/53156

98. Gallinat, A.S., R.B. Primack, and D.L. Wagner, 2015: Autumn, the neglected season in climate change research. *Trends in Ecology & Evolution*, **30** (3), 169-176. http://dx.doi.org/10.1016/j.tree.2015.01.004

99. Zuckerberg, B., A.M. Woods, and W.F. Porter, 2009: Poleward shifts in breeding bird distributions in New York State. *Global Change Biology*, **15** (8), 1866-1883. http://dx.doi.org/10.1111/j.1365-2486.2009.01878.x

100. Gill, A.L., A.S. Gallinat, R. Sanders-DeMott, A.J. Rigden, D.J. Short Gianotti, J.A. Mantooth, and P.H. Templer, 2015: Changes in autumn senescence in northern hemisphere deciduous trees: A meta-analysis of autumn phenology studies. *Annals of Botany*, **116** (6), 875-888. http://dx.doi.org/10.1093/aob/mcv055

101. Leuzinger, S., G. Zotz, R. Asshoff, and C. Körner, 2005: Responses of deciduous forest trees to severe drought in Central Europe. *Tree Physiology*, **25** (6), 641-650. http://dx.doi.org/10.1093/treephys/25.6.641

102. Dupigny-Giroux, L.-A., 2001: Towards characterizing and planning for drought in vermont-part I: A climatological perspective. *JAWRA Journal of the American Water Resources Association*, **37** (3), 505-525. http://dx.doi.org/10.1111/j.1752-1688.2001.tb05489.x

103. Archetti, M., A.D. Richardson, J. O'Keefe, and N. Delpierre, 2013: Predicting climate change impacts on the amount and duration of autumn colors in a New England forest. *PLOS ONE*, **8** (3), e57373. http://dx.doi.org/10.1371/journal.pone.0057373

104. Notaro, M., D. Lorenz, C. Hoving, and M. Schummer, 2014: Twenty-first-century projections of snowfall and winter severity across central-eastern North America. *Journal of Climate*, **27** (17), 6526-6550. http://dx.doi.org/10.1175/jcli-d-13-00520.1

105. Demaria, E.M.C., J.K. Roundy, S. Wi, and R.N. Palmer, 2016: The effects of climate change on seasonal snowpack and the hydrology of the Northeastern and Upper Midwest United States. *Journal of Climate*, **29** (18), 6527-6541. http://dx.doi.org/10.1175/jcli-d-15-0632.1

106. Feng, S. and Q. Hu, 2007: Changes in winter snowfall/precipitation ratio in the contiguous United States. *Journal of Geophysical Research*, **112** (D15), D15109. http://dx.doi.org/10.1029/2007JD008397

107. Kunkel, K.E., M. Palecki, L. Ensor, K.G. Hubbard, D. Robinson, K. Redmond, and D. Easterling, 2009: Trends in twentieth-century US snowfall using a quality-controlled dataset. *Journal of Atmospheric and Oceanic Technology*, **26**, 33-44. http://dx.doi.org/10.1175/2008JTECHA1138.1

108. Ning, L. and R.S. Bradley, 2015: Snow occurrence changes over the central and eastern United States under future warming scenarios. *Scientific Reports*, **5**, 17073. http://dx.doi.org/10.1038/srep17073

109. Knowles, N., M.D. Dettinger, and D.R. Cayan, 2006: Trends in snowfall versus rainfall in the western United States. *Journal of Climate*, **19** (18), 4545-4559. http://dx.doi.org/10.1175/JCLI3850.1

110. Kunkel, K.E., D.A. Robinson, S. Champion, X. Yin, T. Estilow, and R.M. Frankson, 2016: Trends and extremes in Northern Hemisphere snow characteristics. *Current Climate Change Reports*, **2** (2), 65-73. http://dx.doi.org/10.1007/s40641-016-0036-8

111. Hodgkins, G.A., 2013: The importance of record length in estimating the magnitude of climatic changes: An example using 175 years of lake ice-out dates in New England. *Climatic Change*, **119** (3), 705-718. http://dx.doi.org/10.1007/s10584-013-0766-8

112. Dudley, R.W., G.A. Hodgkins, M.R. McHale, M.J. Kolian, and B. Renard, 2017: Trends in snowmelt-related streamflow timing in the conterminous United States. *Journal of Hydrology*, **547**, 208-221. http://dx.doi.org/10.1016/j.jhydrol.2017.01.051

113. Poff, N.L.R., M.M. Brinson, and J.W. Day, 2002: *Aquatic Ecosystems & Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States*. Pew Center on Global Climate Change Arlington, Virginia, 56 pp. https://www.pewtrusts.org/-/media/legacy/uploadedfiles/wwwpewtrustsorg/reports/protecting_ocean_life/envclimateaquaticecosystemspdf.pdf

114. Hay, L.E., S.L. Markstrom, and C. Ward-Garrison, 2011: Watershed-scale response to climate change through the twenty-first century for selected basins across the United States. *Earth Interactions*, **15** (17), 1-37. http://dx.doi.org/10.1175/2010ei370.1

115. Scott, D., J. Dawson, and B. Jones, 2008: Climate change vulnerability of the US Northeast winter recreation– tourism sector. *Mitigation and Adaptation Strategies for Global Change*, **13** (5), 577-596. http://dx.doi.org/10.1007/s11027-007-9136-z

116. Hagenstad, M., E. Burakowski, and R. Hill, 2018: The Economic Contributions of Winter Sports in a Changing Climate. Protect Our Winters and REI Co-op, Boulder, CO, 69 pp. https://protectourwinters.org/2018-economic-report/

117. Dawson, J. and D. Scott, 2013: Managing for climate change in the alpine ski sector. *Tourism Management*, **35**, 244-254. http://dx.doi.org/10.1016/j.tourman.2012.07.009

118. Wobus, C., E.E. Small, H. Hosterman, D. Mills, J. Stein, M. Rissing, R. Jones, M. Duckworth, R. Hall, M. Kolian, J. Creason, and J. Martinich, 2017: Projected climate change impacts on skiing and snowmobiling: A case study of the United States. *Global Environmental Change*, **45**, 1-14. http://dx.doi.org/10.1016/j.gloenvcha.2017.04.006

119. Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles, 2007: Ch. 3: Marine impacts. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment* (NECIA). Union of Concerned Scientists Cambridge, MA, 39-46. http://www.climatechoices.org/assets/documents/climatechoices/confronting-climate-change-in-the-u-s-northeast.pdf

120. Dawson, J., D. Scott, and M. Havitz, 2013: Skier demand and behavioural adaptation to climate change in the US Northeast. *Leisure/Loisir*, **37** (2), 127-143. http://dx.doi.org/10.1080/14927713.2013.805037

121. Hamilton, L.C., C. Brown, and B.D. Keim, 2007: Ski areas, weather and climate: Time series models for New England case studies. *International Journal of Climatology*, **27** (15), 2113-2124. http://dx.doi.org/10.1002/joc.1502

122. USDA, 2014: 2012 Census of Agriculture. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington, DC, 695 pp. http://www.agcensus.usda.gov/Publications/2012/

123. Hsiang, S., R. Kopp, A. Jina, J. Rising, M. Delgado, S. Mohan, D.J. Rasmussen, R. Muir-Wood, P. Wilson, M. Oppenheimer, K. Larsen, and T. Houser, 2017: Estimating economic damage from climate change in the United States. *Science*, **356** (6345), 1362-1369. http://dx.doi.org/10.1126/science.aal4369

124. Kunkel, K.E., T.R. Karl, D.R. Easterling, K. Redmond, J. Young, X. Yin, and P. Hennon, 2013: Probable maximum precipitation and climate change. *Geophysical Research Letters*, **40** (7), 1402-1408. http://dx.doi.org/10.1002/grl.50334

125. Guilbert, J., A.K. Betts, D.M. Rizzo, B. Beckage, and A. Bomblies, 2015: Characterization of increased persistence and intensity of precipitation in the northeastern United States. *Geophysical Research Letters*, **42** (6), 1888-1893. http://dx.doi.org/10.1002/2015GL063124

126. Hamza, M.A. and W.K. Anderson, 2005: Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil and Tillage Research*, **82** (2), 121-145. http://dx.doi.org/10.1016/j.still.2004.08.009

127. Tomasek, B.J., M.M. Williams, II, and A.S. Davis, 2017: Changes in field workability and drought risk from projected climate change drive spatially variable risks in Illinois cropping systems. PLOS ONE, **12** (2), e0172301. http://dx.doi.org/10.1371/journal.pone.0172301

128. Bloomfield, J.P., R.J. Williams, D.C. Gooddy, J.N. Cape, and P. Guha, 2006: Impacts of climate change on the fate and behaviour of pesticides in surface and groundwater—a UK perspective. *Science of the Total Environment*, **369** (1), 163-177. http://dx.doi.org/10.1016/j.scitotenv.2006.05.019

129. Hristov, A.N., A.T. Degaetano, C.A. Rotz, E. Hoberg, R.H. Skinner, T. Felix, H. Li, P.H. Patterson, G. Roth, M. Hall, T.L. Ott, L.H. Baumgard, W. Staniar, R.M. Hulet, C.J. Dell, A.F. Brito, and D.Y. Hollinger, 2017: Climate change effects on livestock in the Northeast US and strategies for adaptation. *Climatic Change*. http://dx.doi.org/10.1007/s10584-017-2023-z

130. Sterk, A., J. Schijven, A.M. de Roda Husman, and T. de Nijs, 2016: Effect of climate change on runoff of *Campylobacter* and *Cryptosporidium* from land to surface water. *Water Research*, **95**, 90-102. http://dx.doi.org/10.1016/j.watres.2016.03.005

131. Jones, R., C. Travers, C. Rodgers, B. Lazar, E. English, J. Lipton, J. Vogel, K. Strzepek, and J. Martinich, 2013: Climate change impacts on freshwater recreational fishing in the United States. *Mitigation and Adaptation Strategies for Global Change*, **18** (6), 731-758. http://dx.doi.org/10.1007/s11027-012-9385-3

132. Xenopoulos, M.A. and D.M. Lodge, 2006: Going with the flow: Using species–discharge relationships to forecast losses in fish biodiversity. *Ecology*, **87** (8), 1907-1914. http://dx.doi.org/10.1890/0012-9658(2006)87[1907:GWTFUS]2.0.CO;2

133. Spooner, D.E., M.A. Xenopoulos, C. Schneider, and D.A. Woolnough, 2011: Coextirpation of host-affiliate relationships in rivers: The role of climate change, water withdrawal, and host-specificity. *Global Change Biology*, **17** (4), 1720-1732. http://dx.doi.org/10.1111/j.1365-2486.2010.02372.x

134. Small, D., S. Islam, and R.M. Vogel, 2006: Trends in precipitation and streamflow in the eastern U.S.: Paradox or perception? *Geophysical Research Letters*, **33** (3), L03403. http://dx.doi.org/10.1029/2005gl024995

135. Whitfield, P.H., 2012: Floods in future climates: A review. *Journal of Flood Risk Management*, **5** (4), 336-365. http://dx.doi.org/10.1111/j.1753-318X.2012.01150.x

136. Ivancic, T.J. and S.B. Shaw, 2015: Examining why trends in very heavy precipitation should not be mistaken for trends in very high river discharge. *Climatic Change*, **133** (4), 681-693. http://dx.doi.org/10.1007/s10584-015-1476-1

137. Frei, A., K.E. Kunkel, and A. Matonse, 2015: The seasonal nature of extreme hydrological events in the northeastern United States. *Journal of Hydrometeorology*, **16** (5), 2065-2085. http://dx.doi.org/10.1175/JHM-D-14-0237.1

138. Kam, J. and J. Sheffield, 2016: Changes in the low flow regime over the eastern United States (1962–2011): Variability, trends, and attributions. *Climatic Change*, **135** (3), 639-653. http://dx.doi.org/10.1007/s10584-015-1574-0

139. Ahn, K.-H. and R.N. Palmer, 2016: Trend and variability in observed hydrological extremes in the United States. *Journal of Hydrologic Engineering*, **21** (2), 04015061. http://dx.doi.org/10.1061/(ASCE)HE.1943-5584.0001286

140. EPA, 2016: Climate Change Indicators in the United States, 2016. 4th edition. EPA 430-R-16-004. U.S. Environmental Protection Agency, Washington, DC, 96 pp. https://www.epa.gov/sites/production/files/2016-08/documents/climate_indicators_2016.pdf

141. Kramer, R.J., L. Bounoua, P. Zhang, R.E. Wolfe, T.G. Huntington, M.L. Imhoff, K. Thome, and G.L. Noyce, 2015: Evapotranspiration trends over the eastern United States during the 20th century. *Hydrology*, **2** (2), 93-111. http://dx.doi.org/10.3390/hydrology2020093

142. Demaria, E.M.C., R.N. Palmer, and J.K. Roundy, 2016: Regional climate change projections of streamflow characteristics in the Northeast and Midwest U.S. *Journal of Hydrology: Regional Studies*, **5**, 309-323. http://dx.doi.org/10.1016/j.ejrh.2015.11.007

143. Hare, J.A., W.E. Morrison, M.W. Nelson, M.M. Stachura, E.J. Teeters, R.B. Griffis, M.A. Alexander, J.D. Scott, L. Alade, R.J. Bell, A.S. Chute, K.L. Curti, T.H. Curtis, D. Kircheis, J.F. Kocik, S.M. Lucey, C.T. McCandless, L.M. Milke, D.E. Richardson, E. Robillard, H.J. Walsh, M.C. McManus, K.E. Marancik, and C.A. Griswold, 2016: A vulnerability assessment of fish and invertebrates to climate change on the northeast U.S. continental shelf. *PLOS ONE*, **11** (2), e0146756. http://dx.doi.org/10.1371/journal.pone.0146756

144. Collins, S.D. and N.E. McIntyre, 2017: Extreme loss of diversity of riverine dragonflies in the northeastern US is predicted in the face of climate change *Bulletin of American Odonatology*, **12** (2), 7-19.

145. Groffman, P.M., P. Kareiva, S. Carter, N.B. Grimm, J. Lawler, M. Mack, V. Matzek, and H. Tallis, 2014: Ch. 8: Ecosystems, biodiversity, and ecosystem services. *Climate Change Impacts in the United States: The Third National Climate Assessment*. Melillo, J.M., Terese (T.C.) Richmond, and G.W. Yohe, Eds. U.S. Global Change Research Program, Washington, DC, 195-219. http://dx.doi.org/10.7930/J0TD9V7H

146. Lane, D., R. Jones, D. Mills, C. Wobus, R.C. Ready, R.W. Buddemeier, E. English, J. Martinich, K. Shouse, and H. Hosterman, 2015: Climate change impacts on freshwater fish, coral reefs, and related ecosystem services in the United States. *Climatic Change*, **131** (1), 143-157. http://dx.doi.org/10.1007/s10584-014-1107-2

147. Mcleod, E., G.L. Chmura, S. Bouillon, R. Salm, M. Björk, C.M. Duarte, C.E. Lovelock, W.H. Schlesinger, and B.R. Silliman, 2011: A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment*, **9** (10), 552-560. http://dx.doi.org/10.1890/110004

148. Fagherazzi, S., 2014: Coastal processes: Storm-proofing with marshes. *Nature Geoscience*, **7** (10), 701-702. http://dx.doi.org/10.1038/ngeo2262

149. Möller, I., M. Kudella, F. Rupprecht, T. Spencer, M. Paul, B.K. van Wesenbeeck, G. Wolters, K. Jensen, T.J. Bouma, M. Miranda-Lange, and S. Schimmels, 2014: Wave attenuation over coastal salt marshes under storm surge conditions. *Nature Geoscience*, **7** (10), 727-731. http://dx.doi.org/10.1038/ngeo2251

150. Balouskus, R.G. and T.E. Targett, 2012: Egg deposition by Atlantic silverside, *Menidia menidia*: Substrate utilization and comparison of natural and altered shoreline type. *Estuaries and Coasts*, **35** (4), 1100-1109. http://dx.doi.org/10.1007/s12237-012-9495-x

151. Powell, E.J., M.C. Tyrrell, A. Milliken, J.M. Tirpak, and M.D. Staudinger, 2017: A synthesis of thresholds for focal species along the U.S. Atlantic and Gulf Coasts: A review of research and applications. *Ocean & Coastal Management*, **148**, 75-88. http://dx.doi.org/10.1016/j.ocecoaman.2017.07.012

152. MERCINA Working Group, A.J. Pershing, C.H. Greene, C. Hannah, D. Sameoto, E. Head, D.G. Mountain, J.W. Jossi, M.C. Benfield, P.C. Reid, and T.G. Durbin, 2015: Oceanographic responses to climate in the northwest Atlantic. *Oceanography*, **14** (3), 76-82. http://dx.doi.org/10.5670/oceanog.2001.25

153. Shearman, R.K. and S.J. Lentz, 2010: Long-term sea surface temperature variability along the U.S. East Coast. *Journal of Physical Oceanography*, **40** (5), 1004-1017. http://dx.doi.org/10.1175/2009jpo4300.1

154. Thomas, A.C., A.J. Pershing, K.D. Friedland, J.A. Nye, K.E. Mills, M.A. Alexander, N.R. Record, R. Weatherbee, and M.E. Henderson, 2017: Seasonal trends and phenology shifts in sea surface temperature on the North American northeastern continental shelf. *Elementa: Science of the Anthropocene*, **5**, 48. http://dx.doi.org/10.1525/elementa.240

155. Mills, K.E., A.J. Pershing, C.J. Brown, Y. Chen, F.-S. Chiang, D.S. Holland, S. Lehuta, J.A. Nye, J.C. Sun, A.C. Thomas, and R.A. Wahle, 2013: Fisheries management in a changing climate: Lessons from the 2012 ocean heat wave in the northwest Atlantic. *Oceanography*, **26** (2), 191-195. http://dx.doi.org/10.5670/oceanog.2013.27

156. Chen, K., G.G. Gawarkiewicz, S.J. Lentz, and J.M. Bane, 2014: Diagnosing the warming of the northeastern U.S. coastal ocean in 2012: A linkage between the atmospheric jet stream variability and ocean response. *Journal of Geophysical Research Oceans*, **119** (1), 218-227. http://dx.doi.org/10.1002/2013JC009393

157. Chen, K., G. Gawarkiewicz, Y.-O. Kwon, and W.G. Zhang, 2015: The role of atmospheric forcing versus ocean advection during the extreme warming of the Northeast U.S. continental shelf in 2012. *Journal of Geophysical Research Oceans*, **120** (6), 4324-4339. http://dx.doi.org/10.1002/2014JC010547

158. Friedland, K.D., R.T. Leaf, J. Kane, D. Tommasi, R.G. Asch, N. Rebuck, R. Ji, S.I. Large, C. Stock, and V.S. Saba, 2015: Spring bloom dynamics and zooplankton biomass response on the US Northeast Continental Shelf. *Continental Shelf Research*, **102**, 47-61. http://dx.doi.org/10.1016/j.csr.2015.04.005

159. Runge, J.A., R. Ji, C.R.S. Thompson, N.R. Record, C. Chen, D.C. Vandemark, J.E. Salisbury, and F. Maps, 2015: Persistence of *Calanus finmarchicus* in the western Gulf of Maine during recent extreme warming. *Journal of Plankton Research*, **37** (1), 221-232. http://dx.doi.org/10.1093/plankt/fbu098

160. Pace, R.M., P.J. Corkeron, and S.D. Kraus, 2017: State–space mark–recapture estimates reveal a recent decline in abundance of North Atlantic right whales. *Ecology and Evolution*, **7** (21), 8730-8741. http://dx.doi.org/10.1002/ece3.3406

161. Henry, A.M. and T.R. Johnson, 2015: Understanding social resilience in the Maine lobster industry. *Marine and Coastal Fisheries*, **7** (1), 33-43. http://dx.doi.org/10.1080/19425120.2014.984086

162. ESRL, 2017: NOAA Climate Change Portal. NOAA Earth System Research Laboratory (ESRL), Boulder, CO. https://www.esrl.noaa.gov/psd/ipcc/

163. Richards, R.A., 2012: Phenological shifts in hatch timing of northern shrimp *Pandalus borealis*. *Marine Ecology Progress Series*, **456**, 149-158. http://dx.doi.org/10.3354/meps09717

164. Walsh, H.J., D.E. Richardson, K.E. Marancik, and J.A. Hare, 2015: Long-term changes in the distributions of larval and adult fish in the northeast U.S. shelf ecosystem. *PLOS ONE*, **10** (9), e0137382. http://dx.doi.org/10.1371/journal.pone.0137382

165. Juanes, F., S. Gephard, and K.F. Beland, 2004: Long-term changes in migration timing of adult Atlantic salmon (*Salmo salar*) at the southern edge of the species distribution. *Canadian Journal of Fisheries and Aquatic Sciences*, **61** (12), 2392-2400. http://dx.doi.org/10.1139/f04-207

166. Peer, A.C. and T.J. Miller, 2014: Climate change, migration phenology, and fisheries management interact with unanticipated consequences. *North American Journal of Fisheries Management*, **34** (1), 94-110. http://dx.doi.org/10.1080/02755947.2013.847877

167. Friedland, K.D., J.P. Manning, J.S. Link, J.R. Gilbert, A.T. Gilbert, and A.F. O'Connell, 2012: Variation in wind and piscivorous predator fields affecting the survival of Atlantic salmon, *Salmo salar*, in the Gulf of Maine. *Fisheries Management and Ecology*, **19** (1), 22-35. http://dx.doi.org/10.1111/j.1365-2400.2011.00814.x

168. Burke, E., 2012: Massachusetts Large Whale Conservation Program: Final Report: August 1, 2011–June 31, 2012. Massachusetts Division of Marine Fisheries New Bedford, MA, 15 pp. https://www.greateratlantic.fisheries.noaa.gov/protected/grantsresearchprojects/fgp/reports/na11nmf4720046_ma_large_whale_cons_final_progress_report.pdf

169. Lucey, S.M. and J.A. Nye, 2010: Shifting species assemblages in the northeast US continental shelf large marine ecosystem. *Marine Ecology Progress Series*, **415**, 23-33. http://dx.doi.org/10.3354/Meps08743

170. Eckert, R., K. Whitmore, A. Richards, M. Hunter, K. Drew, and M. Appelman, 2016: Stock Status Report for Gulf Of Maine Northern Shrimp—2016. Atlantic States Marine Fisheries Commission, Arlington, VA, 81 pp. http://www.asmfc.org/uploads/file/5823782c2016NorthernShrimpAssessment.pdf

171. Narváez, D.A., D.M. Munroe, E.E. Hofmann, J.M. Klinck, E.N. Powell, R. Mann, and E. Curchitser, 2015: Long-term dynamics in Atlantic surfclam (*Spisula solidissima*) populations: The role of bottom water temperature. *Journal of Marine Systems*, **141**, 136-148. http://dx.doi.org/10.1016/j.jmarsys.2014.08.007

172. Weinberg, J.R., 2005: Bathymetric shift in the distribution of Atlantic surfclams: Response to warmer ocean temperature. *ICES Journal of Marine Science*, **62** (7), 1444-1453. http://dx.doi.org/10.1016/j.icesjms.2005.04.020

173. Hoenig, J., R. Muller, and J. Tremblay, 2015: American Lobster Benchmark Stock Assessment and Peer Review Report. Atlantic States Marine Fisheries Commission, Arlington, VA, 438 pp. http://www.asmfc.org/uploads/file//55d61d73AmLobsterStockAssmt_PeerReviewReport_Aug2015_red2.pdf

174. Castro, K.M., J.S. Cobb, M. Gomez-Chiarri, and M. Tlusty, 2012: Epizootic shell disease in American lobsters *Homarus americanus* in southern New England: Past, present and future. *Diseases of Aquatic Organisms*, **100** (2), 149-158. http://dx.doi.org/10.3354/dao02507

175. Burge, C.A., C.M. Eakin, C.S. Friedman, B. Froelich, P.K. Hershberger, E.E. Hofmann, L.E. Petes, K.C. Prager, E. Weil, B.L. Willis, S.E. Ford, and C.D. Harvell, 2014: Climate change influences on marine infectious diseases: Implications for management and society. *Annual Review of Marine Science*, **6** (1), 249-277. http://dx.doi.org/10.1146/annurev-marine-010213-135029

176. Pinsky, M.L. and M. Fogarty, 2012: Lagged social–ecological responses to climate and range shifts in fisheries. *Climatic Change*, **115** (3-4), 883-891. http://dx.doi.org/10.1007/s10584-012-0599-x

177. McCay, B.J., 2012: Shifts in fishing grounds. *Nature Climate Change*, **2**, 840-841. http://dx.doi.org/10.1038/nclimate1765

178. Pinsky, M.L. and N.J. Mantua, 2014: Emerging adaptation approaches for climate-ready fisheries management. *Oceanography*, **27** (4), 146-159. http://dx.doi.org/10.5670/oceanog.2014.93

179. Stoll, J.S., C.M. Beitl, and J.A. Wilson, 2016: How access to Maine's fisheries has changed over a quarter century: The cumulative effects of licensing on resilience. *Global Environmental Change*, **37**, 79-91. http://dx.doi.org/10.1016/j.gloenvcha.2016.01.005

180. Pershing, A.J., M.A. Alexander, C.M. Hernandez, L.A. Kerr, A. Le Bris, K.E. Mills, J.A. Nye, N.R. Record, H.A. Scannell, J.D. Scott, G.D. Sherwood, and A.C. Thomas, 2016: Response to Comments on "Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery." *Science*, **352** (6284), 423-423. http://dx.doi.org/10.1126/science.aae0463

181. Wang, Z.A., R. Wanninkhof, W.-J. Cai, R.H. Byrne, X. Hu, T.-H. Peng, and W.-J. Huang, 2013: The marine inorganic carbon system along the Gulf of Mexico and Atlantic coasts of the United States: Insights from a transregional coastal carbon study. *Limnology and Oceanography*, **58** (1), 325-342. http://dx.doi.org/10.4319/lo.2013.58.1.0325

182. Gledhill, D.K., M.M. White, J. Salisbury, H. Thomas, I. Mlsna, M. Liebman, B. Mook, J. Grear, A.C. Candelmo, R.C. Chambers, C.J. Gobler, C.W. Hunt, A.L. King, N.N. Price, S.R. Signorini, E. Stancioff, C. Stymiest, R.A. Wahle, J.D. Waller, N.D. Rebuck, Z.A. Wang, T.L. Capson, J.R. Morrison, S.R. Cooley, and S.C. Doney, 2015: Ocean and coastal acidification off New England and Nova Scotia. *Oceanography*, **28** (2), 182-197. http://dx.doi.org/10.5670/oceanog.2015.41

183. Cai, W.-J., X. Hu, W.-J. Huang, M.C. Murrell, J.C. Lehrter, S.E. Lohrenz, W.-C. Chou, W. Zhai, J.T. Hollibaugh, Y. Wang, P. Zhao, X. Guo, K. Gundersen, M. Dai, and G.-C. Gong, 2011: Acidification of subsurface coastal waters enhanced by eutrophication. *Nature Geoscience*, **4** (11), 766-770. http://dx.doi.org/10.1038/ngeo1297

184. Salisbury, J., M. Green, C. Hunt, and J. Campbell, 2008: Coastal acidification by rivers: A threat to shellfish? *Eos, Transactions, American Geophysical Union*, **89** (50), 513-513. http://dx.doi.org/10.1029/2008EO500001

185. Wallace, R.B., H. Baumann, J.S. Grear, R.C. Aller, and C.J. Gobler, 2014: Coastal ocean acidification: The other eutrophication problem. *Estuarine, Coastal and Shelf Science*, **148**, 1-13. http://dx.doi.org/10.1016/j.ecss.2014.05.027

186. Ekstrom, J.A., L. Suatoni, S.R. Cooley, L.H. Pendleton, G.G. Waldbusser, J.E. Cinner, J. Ritter, C. Langdon, R. van Hooidonk, D. Gledhill, K. Wellman, M.W. Beck, L.M. Brander, D. Rittschof, C. Doherty, P.E.T. Edwards, and R. Portela, 2015: Vulnerability and adaptation of US shellfisheries to ocean acidification. *Nature Climate Change*, **5** (3), 207-214. http://dx.doi.org/10.1038/nclimate2508

187. U.S. Federal Government, 2017: U.S. Climate Resilience Toolkit: Oyster Growers Prepare for Changing Ocean Chemistry [web page]. U.S. Global Change Research Program, Washington, DC. https://toolkit.climate.gov/case-studies/oyster-growers-prepare-changing-ocean-chemistry

188. Grieve, B.D., J.A. Hare, and V.S. Saba, 2017: Projecting the effects of climate change on *Calanus finmarchicus* distribution within the U.S. Northeast Continental Shelf. *Scientific Reports*, **7** (1), 6264. http://dx.doi.org/10.1038/s41598-017-06524-1

189. Kleisner, K.M., M.J. Fogarty, S. McGee, J.A. Hare, S. Moret, C.T. Perretti, and V.S. Saba, 2017: Marine species distribution shifts on the U.S. Northeast Continental Shelf under continued ocean warming. *Progress in Oceanography*, **153**, 24-36. http://dx.doi.org/10.1016/j.pocean.2017.04.001

190. Fogarty, M., L. Incze, K. Hayhoe, D. Mountain, and J. Manning, 2008: Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. *Mitigation and Adaptation Strategies for Global Change*, **13** (5-6), 453-466. http://dx.doi.org/10.1007/s11027-007-9131-4

191. Cooley, S.R., J.E. Rheuban, D.R. Hart, V. Luu, D.M. Glover, J.A. Hare, and S.C. Doney, 2015: An integrated assessment model for helping the United States sea scallop (*Placopecten magellanicus*) fishery plan ahead for ocean acidification and warming. *PLOS ONE*, **10** (5), e0124145. http://dx.doi.org/10.1371/journal.pone.0124145

192. Greene, C.H. and A.J. Pershing, 2004: Climate and the conservation biology of North Atlantic right whales: The right whale at the wrong time? *Frontiers in Ecology and the Environment*, **2** (1), 29-34. http://dx.doi.org/10.1890/1540-9295(2004)002[0029:CATCBO]2.0.CO;2

193. Breece, M.W., M.J. Oliver, M.A. Cimino, and D.A. Fox, 2013: Shifting distributions of adult Atlantic sturgeon amidst post-industrialization and future impacts in the Delaware River: A maximum entropy approach. PLOS ONE, **8** (11), e81321. http://dx.doi.org/10.1371/journal.pone.0081321

194. Mills, K.E., A.J. Pershing, T.F. Sheehan, and D. Mountain, 2013: Climate and ecosystem linkages explain widespread declines in North American Atlantic salmon populations. *Global Change Biology*, **19** (10), 3046-3061. http://dx.doi.org/10.1111/gcb.12298

195. Meyer-Gutbrod, E.L. and C.H. Greene, 2018: Uncertain recovery of the North Atlantic right whale in a changing ocean. *Global Change Biology*, **24** (1), 455-464. http://dx.doi.org/10.1111/gcb.13929

196. Steneck, R.S., T.P. Hughes, J.E. Cinner, W.N. Adger, S.N. Arnold, F. Berkes, S.A. Boudreau, K. Brown, C. Folke, L. Gunderson, P. Olsson, M. Scheffer, E. Stephenson, B. Walker, J. Wilson, and B. Worm, 2011: Creation of a gilded trap by the high economic value of the Maine lobster fishery. *Conservation Biology*, **25** (5), 904-912. http://dx.doi.org/10.1111/j.1523-1739.2011.01717.x

197. Colburn, L.L. and M. Jepson, 2012: Social indicators of gentrification pressure in fishing communities: A context for social impact assessment. *Coastal Management*, **40** (3), 289-300. http://dx.doi.org/10.1080/08920753.2012.677635

198. Northeast Fisheries Science Center (NEFSC), 2013: 55th Northeast Regional Stock Assessment Workshop (55th SAW): Assessment Summary Report. NEFSC Reference Document 13-01. NOAA's National Marine Fisheries Service, Woods Hole, MA, 41 pp. https://www.nefsc.noaa.gov/publications/crd/crd1301/crd1301.pdf

199. Palmer, M.C., 2014: 2014 Assessment Update Report of the Gulf of Maine Atlantic Cod Stock. Northeast Fisheries Science Center Reference Document 14-14. NOAA's National Marine Fisheries Service, Woods Hole, MA, 41 pp. http://dx.doi.org/10.7289/V5V9862C

200. Powell, E.N., J.M. Klinck, D.M. Munroe, E.E. Hofmann, P. Moreno, and R. Mann, 2015: The value of captains' behavioral choices in the success of the surf clam (*Spisula solidissima*) fishery on the US Mid-Atlantic coast: A model evaluation. *Journal Northwest Atlantic Fisheries Science*, **47**, 1-27. http://journal.nafo.int/Volumes/Articles/ID/617/The-Value-of-Captains-Behavioral-Choices-in-the-Success-of-the-Surfclam-emSpisula-solidissimaem-Fishery-on-the-US-Mid-Atlantic-Coast-a-Model-Evaluation

201. Hamilton, L.C., 2007: Climate, fishery and society interactions: Observations from the North Atlantic. *Deep Sea Research Part II: Topical Studies in Oceanography*, **54** (23), 2958-2969. http://dx.doi.org/10.1016/j.dsr2.2007.08.020

202. Clay, P.M. and J. Olson, 2008: Defining "fishing communities": Vulnerability and the Magnuson-Stevens Fishery Conservation and Management Act. *Human Ecology Review*, **15** (2), 143-160. http://www.humanecologyreview.org/pastissues/her152/clayolson.pdf

203. Thunberg, E.M. and S.J. Correia, 2015: Measures of fishing fleet diversity in the New England groundfish fishery. *Marine Policy*, **58**, 6-14. http://dx.doi.org/10.1016/j.marpol.2015.04.005

204. Northeast Fisheries Science Center (NEFSC), 2017: 62nd Northeast Regional Stock Assessment Workshop (62nd SAW): Assessment Report. NEFSC Reference Document 17-03. NOAA's National Marine Fisheries Service, Woods Hole, MA, 822 pp. http://dx.doi.org/10.7289/V5/RD-NEFSC-17-03

205. Boon, J.D., 2012: Evidence of sea level acceleration at U.S. and Canadian tide stations, Atlantic Coast, North America. *Journal of Coastal Research*, **28**, 1437-1445. http://dx.doi.org/10.2112/JCOASTRES-D-12-00102.1

206. Ezer, T. and W.B. Corlett, 2012: Is sea level rise accelerating in the Chesapeake Bay? A demonstration of a novel new approach for analyzing sea level data. *Geophysical Research Letters*, **39** (19), L19605. http://dx.doi.org/10.1029/2012GL053435

207. Sella, G.F., S. Stein, T.H. Dixon, M. Craymer, T.S. James, S. Mazzotti, and R.K. Dokka, 2007: Observation of glacial isostatic adjustment in "stable" North America with GPS. *Geophysical Research Letters*, **34** (2), L02306. http://dx.doi.org/10.1029/2006GL027081

208. Karegar, M.A., T.H. Dixon, and S.E. Engelhart, 2016: Subsidence along the Atlantic Coast of North America: Insights from GPS and late Holocene relative sea level data. *Geophysical Research Letters*, **43** (7), 3126-3133. http://dx.doi.org/10.1002/2016GL068015

209. Love, R., G.A. Milne, L. Tarasov, S.E. Engelhart, M.P. Hijma, K. Latychev, B.P. Horton, and T.E. Törnqvist, 2016: The contribution of glacial isostatic adjustment to projections of sea-level change along the Atlantic and Gulf coasts of North America. *Earth's Future*, **4** (10), 440-464. http://dx.doi.org/10.1002/2016EF000363

210. Kopp, R.E., 2013: Does the mid-Atlantic United States sea level acceleration hot spot reflect ocean dynamic variability? *Geophysical Research Letters*, **40** (15), 3981-3985. http://dx.doi.org/10.1002/grl.50781

211. Rahmstorf, S., J.E. Box, G. Feulner, M.E. Mann, A. Robinson, S. Rutherford, and E.J. Schaffernicht, 2015: Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Climate Change*, **5** (5), 475-480. http://dx.doi.org/10.1038/nclimate2554

212. McCarthy, G.D., I.D. Haigh, J.J.M. Hirschi, J.P. Grist, and D.A. Smeed, 2015: Ocean impact on decadal Atlantic climate variability revealed by sea-level observations. *Nature*, **521**, 508-510. http://dx.doi.org/10.1038/nature14491

213. Valle-Levinson, A., A. Dutton, and J.B. Martin, 2017: Spatial and temporal variability of sea level rise hot spots over the eastern United States. *Geophysical Research Letters*, **44** (15), 7876-7882. http://dx.doi.org/10.1002/2017GL073926

214. Davis, J.L. and N.T. Vinogradova, 2017: Causes of accelerating sea level on the East Coast of North America. *Geophysical Research Letters*, **44** (10), 5133-5141. http://dx.doi.org/10.1002/2017GL072845

215. Goddard, P.B., J. Yin, S.M. Griffies, and S. Zhang, 2015: An extreme event of sea-level rise along the Northeast coast of North America in 2009–2010. *Nature Communications*, **6**, 6346. http://dx.doi.org/10.1038/ncomms7346

216. Sweet, W.V. and J. Park, 2014: From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. *Earth's Future*, **2** (12), 579-600. http://dx.doi.org/10.1002/2014EF000272

217. Ezer, T. and L.P. Atkinson, 2014: Accelerated flooding along the U.S. East Coast: On the impact of sea-level rise, tides, storms, the Gulf Stream, and the North Atlantic Oscillations. *Earth's Future*, **2** (8), 362-382. http://dx.doi.org/10.1002/2014EF000252

218. Morton, R.A. and A.H. Sallenger Jr, 2003: Morphological impacts of extreme storms on sandy beaches and barriers. *Journal of Coastal Research*, **19** (3), 560-573. http://pubs.er.usgs.gov/publication/70025481

219. Leonardi, N., N.K. Ganju, and S. Fagherazzi, 2016: A linear relationship between wave power and erosion determines salt-marsh resilience to violent storms and hurricanes. *Proceedings of the National Academy of Sciences of the United States of America*, **113** (1), 64-68. http://dx.doi.org/10.1073/pnas.1510095112

220. Tebaldi, C., B.H. Strauss, and C.E. Zervas, 2012: Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters*, **7** (1), 014032. http://dx.doi.org/10.1088/1748-9326/7/1/014032

221. Woodruff, J.D., J.L. Irish, and S.J. Camargo, 2013: Coastal flooding by tropical cyclones and sea-level rise. *Nature*, **504** (7478), 44-52. http://dx.doi.org/10.1038/nature12855

222. Marcy, D., W. Brooks, K. Draganov, B. Hadley, C. Haynes, N. Herold, J. McCombs, M. Pendleton, S. Ryan, K. Schmid, M. Sutherland, and K. Waters, 2011: New mapping tool and techniques for visualizing sea level rise and coastal flooding impacts. *Solutions to Coastal Disasters* 2011. 474-490. http://dx.doi.org/10.1061/41185(417)42

223. Strauss, B.H., R. Ziemlinski, J.L. Weiss, and J.T. Overpeck, 2012: Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. *Environmental Research Letters*, **7** (1), 014033. http://dx.doi.org/10.1088/1748-9326/7/1/014033

224. Morris, J.T., P.V. Sundareshwar, C.T. Nietch, B. Kjerfve, and D.R. Cahoon, 2002: Responses of coastal wetlands to rising sea level. *Ecology*, **83** (10), 2869-2877. http://dx.doi.org/10.1890/0012-9658(2002)083[2869:ROCWTR]2.0.CO;2

225. Kirwan, M.L. and J.P. Megonigal, 2013: Tidal wetland stability in the face of human impacts and sea-level rise. *Nature*, **504** (7478), 53-60. http://dx.doi.org/10.1038/nature12856

226. FitzGerald, D.M., M.S. Fenster, B.A. Argow, and I.V. Buynevich, 2008: Coastal impacts due to sea-level rise. *Annual Review of Earth and Planetary Sciences*. Annual Reviews, Palo Alto, 601-647. http://dx.doi.org/10.1146/annurev.earth.35.031306.140139

227. Arkema, K.K., G. Guannel, G. Verutes, S.A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo, and J.M. Silver, 2013: Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change*, **3** (10), 913-918. http://dx.doi.org/10.1038/nclimate1944

228. Waycott, M., C.M. Duarte, T.J. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck, Jr., A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, F.T. Short, and S.L. Williams, 2009: Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, **106** (30), 12377-81. http://dx.doi.org/10.1073/pnas.0905620106

229. Gieder, K.D., S.M. Karpanty, J.D. Fraser, D.H. Catlin, B.T. Gutierrez, N.G. Plant, A.M. Turecek, and E. Robert Thieler, 2014: A Bayesian network approach to predicting nest presence of the federally-threatened piping plover (*Charadrius melodus*) using barrier island features. *Ecological Modelling*, **276**, 38-50. http://dx.doi.org/10.1016/j.ecolmodel.2014.01.005

230. Drake, K., H. Halifax, S.C. Adamowicz, and C. Craft, 2015: Carbon sequestration in tidal salt marshes of the northeast United States. *Environmental Management*, **56** (4), 998-1008. http://dx.doi.org/10.1007/s00267-015-0568-z

231. Watson, E.B., K. Szura, C. Wigand, K.B. Raposa, K. Blount, and M. Cencer, 2016: Sea level rise, drought and the decline of *Spartina patens* in New England marshes. *Biological Conservation*, **196**, 173-181. http://dx.doi.org/10.1016/j.biocon.2016.02.011

232. Moseman-Valtierra, S., O.I. Abdul-Aziz, J. Tang, K.S. Ishtiaq, K. Morkeski, J. Mora, R.K. Quinn, R.M. Martin, K. Egan, E.Q. Brannon, J. Carey, and K.D. Kroeger, 2016: Carbon dioxide fluxes reflect plant zonation and belowground biomass in a coastal marsh. *Ecosphere*, **7** (11), e01560. http://dx.doi.org/10.1002/ecs2.1560

233. Jordan, S.J., J. Stoffer, and J.A. Nestlerode, 2011: Wetlands as sinks for reactive nitrogen at continental and global scales: A meta-analysis. *Ecosystems*, **14** (1), 144-155. http://dx.doi.org/10.1007/s10021-010-9400-z

234. Piehler, M.F. and A.R. Smyth, 2011: Habitat-specific distinctions in estuarine denitrification affect both ecosystem function and services. *Ecosphere*, **2** (1), art12. http://dx.doi.org/10.1890/ES10-00082.1

235. Velinsky, D.J., B. Paudel, T. Quirk, M. Piehler, and A. Smyth, 2017: Salt marsh denitrification provides a significant nitrogen sink in Barnegat Bay, New Jersey. *Journal of Coastal Research*, **Special Issue 78**, 70-78. http://dx.doi.org/10.2112/si78-007.1

236. Beavers, R., A. Babson, and C. Schupp, 2016: Coastal Adaptation Strategies Handbook. NPS 999/134090. U.S. Department of the Interior, National Park Service, Washington, DC, 140 pp. https://www.nps.gov/subjects/climatechange/coastalhandbook.htm

237. Schupp, C.A., R.L. Beavers, and M.A. Caffrey, Eds., 2015: *Coastal Adaptation Strategies: Case Studies*. NPS 999/129700. U.S. Department of the Interior, National Park Service, Fort Collins, CO, 60 pp. https://www.nps.gov/subjects/climatechange/upload/2015-11-25-FINAL-CAS-Case-Studies-LoRes.pdf

238. Daigle, J.J. and D. Putnam, 2009: The meaning of a changed environment: Initial assessment of climate change impacts in Maine—Indigenous peoples. *Maine's Climate Future: An Initial Assessment*. Jacobson, G.L., I.J. Fernandez, P.A. Mayewski, and C.V. Schmitt, Eds. University of Maine, Orono, ME, 37-40. http://climatechange.umaine.edu/files/Maines_Climate_Future.pdf

239. Bennett, T.M.B., N.G. Maynard, P. Cochran, R. Gough, K. Lynn, J. Maldonado, G. Voggesser, S. Wotkyns, and K. Cozzetto, 2014: Ch. 12: Indigenous peoples, lands, and resources. *Climate Change Impacts in the United States: The Third National Climate Assessment*. Melillo, J.M., T.C. Richmond, and G.W. Yohe, Eds. U.S. Global Change Research Program, Washington, DC, 297-317. http://dx.doi.org/10.7930/J09G5JR1

240. Brooks, L., 2008: *The Common Pot: The Recovery of Native Space in the Northeast*. Vol. 7, *Indigenous Americas*. University of Minnesota Press, Minneapolis, MN, 408 pp.

241. NCAI, 2015: Tribal Nations and the United States: An Introduction. National Congress of American Indians (NCAI), Washington, DC, 47 pp. http://www.ncai.org/resources/ncai_publications/tribal-nations-and-the-united-states-an-introduction

242. NCSL, 2016: Federal and State Recognized Tribes (Updated October 2016). National Conference of State Legislatures (NCSL), Washington, DC. http://www.ncsl.org/research/state-tribal-institute/list-of-federal-and-state-recognized-tribes.aspx

243. Benally, S., 2014: Tribes in New England stand their ground. *Cultural Survival Quarterly*, **38** (2), 3. https://issuu.com/culturalsurvival/docs/csq-382-june-2014

244. Berkes, F., 2009: Indigenous ways of knowing and the study of environmental change. *Journal of the Royal Society of New Zealand*, **39** (4), 151-156. http://dx.doi.org/10.1080/03014220909510568

245. Keyes, B., 2017: Passamaquoddy Tribe named Project Developer of the Year. Indian Country Today, Verona, NY. https://indiancountrymedianetwork.com/news/environment/passamaquoddy-tribe-named-project-developer-year/

246. Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams, 2013: The impacts of climate change on tribal traditional foods. *Climatic Change*, **120** (3), 545-556. http://dx.doi.org/10.1007/s10584-013-0736-1

247. Church, J.A. and N.J. White, 2011: Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, **32** (4-5), 585-602. http://dx.doi.org/10.1007/s10712-011-9119-1

248. Hay, C.C., E. Morrow, R.E. Kopp, and J.X. Mitrovica, 2015: Probabilistic reanalysis of twentieth-century sea-level rise. *Nature*, **517** (7535), 481-484. http://dx.doi.org/10.1038/nature14093

249. Yin, J., M.E. Schlesinger, and R.J. Stouffer, 2009: Model projections of rapid sea-level rise on the northeast coast of the United States. *Nature Geoscience*, **2** (4), 262-266. http://dx.doi.org/10.1038/ngeo462

250. Yin, J. and P.B. Goddard, 2013: Oceanic control of sea level rise patterns along the East Coast of the United States. *Geophysical Research Letters*, **40** (20), 5514-5520. http://dx.doi.org/10.1002/2013GL057992

251. Kopp, R.E., R.M. Horton, C.M. Little, J.X. Mitrovica, M. Oppenheimer, D.J. Rasmussen, B.H. Strauss, and C. Tebaldi, 2014: Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future*, **2** (8), 383-406. http://dx.doi.org/10.1002/2014EF000239

252. Slangen, A.B.A., J.A. Church, X. Zhang, and D. Monselesan, 2014: Detection and attribution of global mean thermosteric sea level change. *Geophysical Research Letters*, **41** (16), 5951-5959. http://dx.doi.org/10.1002/2014GL061356

253. Knutson, T.R., J.J. Sirutis, M. Zhao, R.E. Tuleya, M. Bender, G.A. Vecchi, G. Villarini, and D. Chavas, 2015: Global projections of intense tropical cyclone activity for the late twenty-first century from dynamical downscaling of CMIP5/RCP4.5 scenarios. *Journal of Climate*, **28** (18), 7203-7224. http://dx.doi.org/10.1175/JCLI-D-15-0129.1

254. Horton, R.M. and J. Liu, 2014: Beyond Hurricane Sandy: What might the future hold for tropical cyclones in the North Atlantic? *Journal of Extreme Events*, **01** (01), 1450007. http://dx.doi.org/10.1142/S2345737614500079

255. Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Extreme storms. *Climate Science Special Report: Fourth National Climate Assessment, Volume I.* Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 257-276. http://dx.doi.org/10.7930/J07S7KXX

256. Birchler, J.J., P.S. Dalyander, H.F. Stockdon, and K.S. Doran, 2015: National assessment of nor'easter-induced coastal erosion hazards: Mid- and northeast Atlantic coast. USGS Open-File Report 2015-1154. U.S. Geological Survey, Reston, VA, 34 pp. http://dx.doi.org/10.3133/ofr20151154

257. Birchler, J.J., H.F. Stockdon, K.S. Doran, and D.M. Thompson, 2014: National Assessment of Hurricane-Induced Coastal Erosion Hazards: Northeast Atlantic Coast. USGS Open-File Report 2014–1243. U.S. Geological Survey, Reston, VA, 34 pp. http://dx.doi.org/10.3133/ofr20141243

258. Doran, K.S., H.F. Stockdon, K.L. Sopkin, D.M. Thompson, and N.G. Plant, 2012: National Assessment of Hurricane-Induced Coastal Erosion Hazards: Mid-Atlantic Coast. USGS Open-File Report 2013–1131. U.S. Geological Survey, Reston, VA. https://pubs.usgs.gov/of/2013/1131/

259. Ganju, N.K., Z. Defne, M.L. Kirwan, S. Fagherazzi, A. D'Alpaos, and L. Carniello, 2017: Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes. *Nature Communcations*, **8**, 14156. http://dx.doi.org/10.1038/ncomms14156

260. Houser, T., S. Hsiang, R. Kopp, K. Larsen, M. Delgado, A. Jina, M. Mastrandrea, S. Mohan, R. Muir-Wood, D.J. Rasmussen, J. Rising, and P. Wilson, 2015: *Economic Risks of Climate Change: An American Prospectus*. Columbia University Press, New York, 384 pp.

261. Eberhardt, A.L., D.M. Burdick, and M. Dionne, 2011: The effects of road culverts on nekton in New England salt marshes: Implications for tidal restoration. *Restoration Ecology*, **19** (6), 776-785. http://dx.doi.org/10.1111/j.1526-100X.2010.00721.x

262. Hapke, C.J., E.A. Himmelstoss, M.G. Kratzmann, J.H. List, and E.R. Thieler, 2011: National assessment of shoreline change: Historical shoreline change along the New England and Mid-Atlantic coasts. USGS Open-File Report 2010-1118. U.S. Geological Survey, Reston, VA, 57 pp. https://pubs.er.usgs.gov/publication/ofr20101118

263. Theuerkauf, E.J., A.B. Rodriguez, S.R. Fegley, and R.A. Luettich, 2014: Sea level anomalies exacerbate beach erosion. *Geophysical Research Letters*, **41** (14), 5139-5147. http://dx.doi.org/10.1002/2014GL060544

264. Rogers, L.J., L.J. Moore, E.B. Goldstein, C.J. Hein, J. Lorenzo-Trueba, and A.D. Ashton, 2015: Anthropogenic controls on overwash deposition: Evidence and consequences. *Journal of Geophysical Research Earth Surface*, **120** (12), 2609-2624. http://dx.doi.org/10.1002/2015JF003634

265. Smith, S.M., 2009: Multi-decadal changes in salt marshes of Cape Cod, MA: Photographic analyses of vegetation loss, species shifts, and geomorphic change. *Northeastern Naturalist*, **16** (2), 183-208. http://dx.doi.org/10.1656/045.016.0203

266. Donnelly, J.P. and M.D. Bertness, 2001: Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. *Proceedings of the National Academy of Sciences of the United States of America*, **98** (25), 14218-14223. http://dx.doi.org/10.1073/pnas.251209298

267. Kolker, A.S., S.L. Goodbred, S. Hameed, and J.K. Cochran, 2009: High-resolution records of the response of coastal wetland systems to long-term and short-term sea-level variability. *Estuarine, Coastal and Shelf Science*, **84** (4), 493-508. http://dx.doi.org/10.1016/j.ecss.2009.06.030

268. Hill, T.D. and S.C. Anisfeld, 2015: Coastal wetland response to sea level rise in Connecticut and New York. *Estuarine, Coastal and Shelf Science*, **163** (Part B), 185-193. http://dx.doi.org/10.1016/j.ecss.2015.06.004

269. Beckett, L.H., A.H. Baldwin, and M.S. Kearney, 2016: Tidal marshes across a Chesapeake Bay subestuary are not keeping up with sea-level rise. PLOS ONE, **11** (7), e0159753. http://dx.doi.org/10.1371/journal.pone.0159753

270. Raposa, K.B., R.L.J. Weber, M.C. Ekberg, and W. Ferguson, 2017: Vegetation dynamics in Rhode Island salt marshes during a period of accelerating sea level rise and extreme sea level events. *Estuaries and Coasts*, **40** (3), 640-650. http://dx.doi.org/10.1007/s12237-015-0018-4

271. Watson, E.B., C. Wigand, E.W. Davey, H.M. Andrews, J. Bishop, and K.B. Raposa, 2017: Wetland loss patterns and inundation-productivity relationships prognosticate widespread salt marsh loss for southern New England. *Estuaries and Coasts*, **40** (3), 662-681. http://dx.doi.org/10.1007/s12237-016-0069-1

272. CCSP, 2009: *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. U.S. Environmental Protection Agency, Washington, DC, 320 pp. http://downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf

273. Field, C.R., C. Gjerdrum, and C.S. Elphick, 2016: Forest resistance to sea-level rise prevents landward migration of tidal marsh. *Biological Conservation*, **201**, 363-369. http://dx.doi.org/10.1016/j.biocon.2016.07.035

274. Kirwan, M.L., G.R. Guntenspergen, A. D'Alpaos, J.T. Morris, S.M. Mudd, and S. Temmerman, 2010: Limits on the adaptability of coastal marshes to rising sea level. *Geophysical Research Letters*, **37** (23), L23401. http://dx.doi.org/10.1029/2010gl045489

275. Cahoon, D.R., D.J. Reed, A.S. Kolker, M.M. Brinson, J.C. Stevenson, S. Riggs, R. Christian, E. Reyes, C. Voss, and D. Kunz, 2009: Coastal wetland sustainability. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. Titus, J.G., Ed. U.S. Climate Change Science Program (CCSP), Washington, DC, 57-72. http://www.globalchange.gov/sites/globalchange/files/sap4-1-final-report-all.pdf

276. Elsey-Quirk, T., D.M. Seliskar, C.K. Sommerfield, and J.L. Gallagher, 2011: Salt marsh carbon pool distribution in a mid-Atlantic lagoon, USA: Sea level rise implications. *Wetlands*, **31** (1), 87-99. http://dx.doi.org/10.1007/s13157-010-0139-2

277. Kirwan, M.L., S. Temmerman, E.E. Skeehan, G.R. Guntenspergen, and S. Fagherazzi, 2016: Overestimation of marsh vulnerability to sea level rise. *Nature Climate Change*, **6** (3), 253-260. http://dx.doi.org/10.1038/nclimate2909

278. Mitchell, M., J. Herman, D.M. Bilkovic, and C. Hershner, 2017: Marsh persistence under sea-level rise is controlled by multiple, geologically variable stressors. *Ecosystem Health and Sustainability*, **3** (10), 1379888. http://dx.doi.org/10.1080/20964129.2017.1396009

279. Gutierrez, B.T., N.G. Plant, E.A. Pendleton, and E.R. Thieler, 2014: Using a Bayesian Network to Predict Shore-Line Change Vulnerability to Sea-Level Rise for the Coasts of the United States. USGS Open-File Report 2014–1083. U.S. Geological Survey, Reston, VA, 26 pp. http://dx.doi.org/10.3133/ofr20141083

280. Gutierrez, B.T., S.J. Williams, and E.R. Thieler, 2009: Ocean coasts. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. Titus, J.G., Ed. U.S. Climate Change Science Program (CCSP), Washington, DC, 43-56. http://www.globalchange.gov/sites/globalchange/files/sap4-1-final-report-all.pdf

281. Barbier, E.B., 2012: Progress and challenges in valuing coastal and marine ecosystem services. *Review of Environmental Economics and Policy*, **6** (1), 1-19. http://dx.doi.org/10.1093/reep/rer017

282. Barbier, E.B., E.W. Koch, B.R. Silliman, S.D. Hacker, E. Wolanski, J. Primavera, E.F. Granek, S. Polasky, S. Aswani, L.A. Cramer, D.M. Stoms, C.J. Kennedy, D. Bael, C.V. Kappel, G.M.E. Perillo, and D.J. Reed, 2008: Coastal ecosystem-based management with nonlinear ecological functions and values. *Science*, **319** (5861), 321-323. http://dx.doi.org/10.1126/science.1150349

283. Masterson, J.P., 2004: Simulated Interaction Between Freshwater and Saltwater and Effects of Ground-Water Pumping and Sea-Level Change, Lower Cape Cod Aquifer System, Massachusetts. USGS Scientific Investigations Report 2004-5014. U.S. Geological Survey, Reston, VA, 78 pp. http://dx.doi.org/10.3133/sir20045014

284. Masterson, J.P., M.N. Fienen, E.R. Thieler, D.B. Gesch, B.T. Gutierrez, and N.G. Plant, 2014: Effects of sea-level rise on barrier island groundwater system dynamics—Ecohydrological implications. *Ecohydrology*, **7** (3), 1064-1071. http://dx.doi.org/10.1002/eco.1442

285. Hauer, M.E., 2017: Migration induced by sea-level rise could reshape the US population landscape. *Nature Climate Change*, **7** (5), 321-325. http://dx.doi.org/10.1038/nclimate3271

286. Colgan, C.S., J. Calil, H. Kite-Powell, D. Jin, and P. Hoagland, 2018: Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region. Center for the Blue Economy of the Middlebury Institute of International Studies at Monterey and the Marine Policy Center of the Woods Hole Oceanographic Institution, Annapolis, MD, 158 pp. http://midatlanticocean.org/wp-content/uploads/2018/05/Climate-Change-Vulnerabilities-in-the-Coastal-Mid-Atlantic-Region.pdf

287. Lin, S., B.A. Fletcher, M. Luo, R. Chinery, and S.-A. Hwang, 2011: Health impact in New York City during the Northeastern blackout of 2003. *Public Health Reports*, **126** (3), 384-93. http://dx.doi.org/10.1177/003335491112600312

288. ASCE, 2014: 2014 Pennsylvania Infrastructure Report Card. American Society of Civil Engineers (ASCE), Washington, DC. https://www.infrastructurereportcard.org/state-item/pennsylvania/

289. Buchanan, M.K., M. Oppenheimer, and R.E. Kopp, 2017: Amplification of flood frequencies with local sea level rise and emerging flood regimes. *Environmental Research Letters*, **12** (6), 064009. http://dx.doi.org/10.1088/1748-9326/aa6cb3

290. Zimmerman, R., C.E. Restrepo, J. Sellers, A. Amirapu, and T.R. Pearson, 2014: Promoting Transportation Flexibility in Extreme Events Through Multi-Modal Connectivity. U.S. Department of Transportation, Region 2 Urban Transportation Research Center; NYU-Wagner, New York, NY, 61 pp. https://wagner.nyu.edu/files/faculty/publications/Final-NYU-Extreme-Events-Research-Report.pdf

291. EIA, various: U.S. Energy Mapping System. U.S. Energy Information Administration (EIA), Washington, DC. https://www.eia.gov/state/maps.php

292. Newport Restoration Foundation, 2017: Keeping History Above Water. Newport Restoration Foundation, Newport RI. http://historyabovewater.org/

293. National Trust for Historic Preservation, 2017: Climate and Culture. National Trust for Historic Preservation, Washington, DC. https://savingplaces.org/climate-and-culture

294. New York City, 2013: Special Initiative for Rebuilding and Resiliency (SIRR) [web site]. Office of the Mayor, New York. https://www1.nyc.gov/site/sirr/index.page

295. Climate Ready Boston Steering Committee, 2016: Climate Ready Boston: Final Report. City of Boston, Boston, MA, 339 pp. https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf

296. City of Philadelphia, 2015: Growing Stronger: Towards a Climate-Ready Philadelphia. Mayor's Office of Sustainability, Philadelphia, PA, various pp. https://beta.phila.gov/documents/growing-stronger-toward-a-climate-ready-philadelphia/

297. City of Pittsburgh, [2018]: Pittsburgh Climate Action Plan 3.0. City Council, PIttsburgh, PA. http://apps.pittsburghpa.gov/redtail/images/645_PCAP_3.0_Presentation.pdf

298. Trtanj, J., L. Jantarasami, J. Brunkard, T. Collier, J. Jacobs, E. Lipp, S. McLellan, S. Moore, H. Paerl, J. Ravenscroft, M. Sengco, and J. Thurston, 2016: Ch. 6: Climate impacts on water-related illness. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. U.S. Global Change Research Program, Washington, DC, 157–188. http://dx.doi.org/10.7930/J03F4MH4

299. Guilbert, J., B. Beckage, J.M. Winter, R.M. Horton, T. Perkins, and A. Bomblies, 2014: Impacts of projected climate change over the Lake Champlain basin in Vermont. *Journal of Applied Meteorology and Climatology*, **53** (8), 1861-1875. http://dx.doi.org/10.1175/jamc-d-13-0338.1

300. Yellen, B., J.D. Woodruff, T.L. Cook, and R.M. Newton, 2016: Historically unprecedented erosion from Tropical Storm Irene due to high antecedent precipitation. *Earth Surface Processes and Landforms*, **41** (5), 677-684. http://dx.doi.org/10.1002/esp.3896

301. Flint, M.M., O. Fringer, S.L. Billington, D. Freyberg, and N.S. Diffenbaugh, 2017: Historical analysis of hydraulic bridge collapses in the continental United States. *Journal of Infrastructure Systems*, **23** (3), 04017005. http://dx.doi.org/10.1061/(ASCE)IS.1943-555X.0000354

302. Tavernia, B.G., M.D. Nelson, P. Caldwell, and G. Sun, 2013: Water stress projections for the northeastern and midwestern United States in 2060: Anthropogenic and ecological consequences. *JAWRA Journal of the American Water Resources Association*, **49** (4), 938-952. http://dx.doi.org/10.1111/jawr.12075

303. Matonse, A.H., D.C. Pierson, A. Frei, M.S. Zion, A. Anandhi, E. Schneiderman, and B. Wright, 2013: Investigating the impact of climate change on New York City's primary water supply. *Climatic Change*, **116** (3), 437-456. http://dx.doi.org/10.1007/s10584-012-0515-4

304. Ahmed, S.N., K.R. Bencala, and C.L. Schultz, 2013: 2010 Washington Metropolitan Area Water Supply Reliability Study Part 2: Potential Impacts of Climate Change. ICPRB Report No. 13-07. Interstate Commission on the Potomac River Basin, Rockville, MD, 77 pp. https://www.potomacriver.org/wp-content/uploads/2014/12/ICPRB13-071.pdf

305. Wellenius, G.A., M.N. Eliot, K.F. Bush, D. Holt, R.A. Lincoln, A.E. Smith, and J. Gold, 2017: Heat-related morbidity and mortality in New England: Evidence for local policy. *Environmental Research*, **156**, 845-853. http://dx.doi.org/10.1016/j.envres.2017.02.005

306. Bobb, J.F., Z. Obermeyer, Y. Wang, and F. Dominici, 2014: Cause-specific risk of hospital admission related to extreme heat in older adults. *JAMA*, **312** (24), 2659-2667. http://dx.doi.org/10.1001/jama.2014.15715

307. Hondula, D.M., R.E. Davis, M.J. Leisten, M.V. Saha, L.M. Veazey, and C.R. Wegner, 2012: Fine-scale spatial variability of heat-related mortality in Philadelphia County, USA, from 1983-2008: A case-series analysis. *Environmental Health*, **11** (1), 16. http://dx.doi.org/10.1186/1476-069x-11-16

308. Klein Rosenthal, J., P.L. Kinney, and K.B. Metzger, 2014: Intra-urban vulnerability to heat-related mortality in New York City, 1997–2006. *Health & Place*, **30**, 45-60. http://dx.doi.org/10.1016/j.healthplace.2014.07.014

309. Gronlund, C.J., A. Zanobetti, G.A. Wellenius, J.D. Schwartz, and M.S. O'Neill, 2016: Vulnerability to renal, heat and respiratory hospitalizations during extreme heat among U.S. elderly. *Climatic Change*, **136** (3), 631-645. http://dx.doi.org/10.1007/s10584-016-1638-9

310. Reid, C.E., M.S. O'Neill, C.J. Gronlund, S.J. Brines, D.G. Brown, A.V. Diez-Roux, and J. Schwartz, 2009: Mapping community determinants of heat vulnerability. *Environmental Health Perspectives*, **117** (11), 1730-1736. http://dx.doi.org/10.1289/ehp.0900683

311. Applebaum, K.M., J. Graham, G.M. Gray, P. LaPuma, S.A. McCormick, A. Northcross, and M.J. Perry, 2016: An overview of occupational risks from climate change. *Current Environmental Health Reports*, **3** (1), 13-22. http://dx.doi.org/10.1007/s40572-016-0081-4

312. Trouet, V., H.F. Diaz, E.R. Wahl, A.E. Viau, R. Graham, N. Graham, and E.R. Cook, 2013: A 1500-year reconstruction of annual mean temperature for temperate North America on decadal-to-multidecadal time scales. *Environmental Research Letters*, **8** (2), 024008. http://dx.doi.org/10.1088/1748-9326/8/2/024008

313. Stone, B.J., J. Vargo, P. Liu, D. Habeeb, A. DeLucia, M. Trail, Y. Hu, and A. Russell, 2014: Avoided heat-related mortality through climate adaptation strategies in three US cities. PLOS ONE, **9** (6), e100852. http://dx.doi.org/10.1371/journal.pone.0100852

314. White-Newsome, J., S. McCormick, N. Sampson, M. Buxton, M. O'Neill, C. Gronlund, L. Catalano, K. Conlon, and E. Parker, 2014: Strategies to reduce the harmful effects of extreme heat events: A four-city study. *International Journal of Environmental Research and Public Health*, **11** (2), 1960-1988. http://dx.doi.org/10.3390/ijerph110201960

315. Gasparrini, A., Y. Guo, M. Hashizume, E. Lavigne, A. Zanobetti, J. Schwartz, A. Tobias, S. Tong, J. Rocklöv, B. Forsberg, M. Leone, M. De Sario, M.L. Bell, Y.-L.L. Guo, C.-f. Wu, H. Kan, S.-M. Yi, M. de Sousa Zanotti Stagliorio Coelho, P.H.N. Saldiva, Y. Honda, H. Kim, and B. Armstrong, 2015: Mortality risk attributable to high and low ambient temperature: A multicountry observational study. *The Lancet*, **386**, 369-375. http://dx.doi.org/10.1016/S0140-6736(14)62114-0

316. Metzger, K.B., K. Ito, and T.D. Matte, 2010: Summer heat and mortality in New York City: How hot is too hot? *Environmental Health Perspectives*, **118** (1), 80. http://dx.doi.org/10.1289/ehp.0900906

317. Gasparrini, A., Y. Guo, M. Hashizume, E. Lavigne, A. Tobias, A. Zanobetti, J.D. Schwartz, M. Leone, P. Michelozzi, H. Kan, S. Tong, Y. Honda, H. Kim, and B.G. Armstrong, 2016: Changes in susceptibility to heat during the summer: A multicountry analysis. *American Journal of Epidemiology*, **183** (11), 1027-1036. http://dx.doi.org/10.1093/aje/kwv260

318. West, J.J., S.J. Smith, R.A. Silva, V. Naik, Y. Zhang, Z. Adelman, M.M. Fry, S. Anenberg, L.W. Horowitz, and J.-F. Lamarque, 2013: Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Climate Change*, **3** (10), 885-889. http://dx.doi.org/10.1038/nclimate2009

319. Garcia-Menendez, F., R.K. Saari, E. Monier, and N.E. Selin, 2015: U.S. air quality and health benefits from avoided climate change under greenhouse gas mitigation. *Environmental Science & Technology*, **49** (13), 7580-7588. http://dx.doi.org/10.1021/acs.est.5b01324

320. Berman, J.D., K. Ebisu, R.D. Peng, F. Dominici, and M.L. Bell, 2017: Drought and the risk of hospital admissions and mortality in older adults in western USA from 2000 to 2013: A retrospective study. *The Lancet Planetary Health*, **1** (1), e17-e25. http://dx.doi.org/10.1016/S2542-5196(17)30002-5

321. Drayna, P., S.L. McLellan, P. Simpson, S.-H. Li, and M.H. Gorelick, 2010: Association between rainfall and pediatric emergency department visits for acute gastrointestinal illness. *Environmental Health Perspectives*, **118** (10), 1439-1443. http://dx.doi.org/10.1289/ehp.0901671

322. Jagai, J.S., Q. Li, S. Wang, K.P. Messier, T.J. Wade, and E.D. Hilborn, 2015: Extreme precipitation and emergency room visits for gastrointestinal illness in areas with and without combined sewer systems: An analysis of Massachusetts data, 2003-2007. *Environmental Health Perspectives*, **123** (9), 873-879. http://dx.doi.org/10.1289/ehp.1408971

323. Bobb, J.F., K.K.L. Ho, R.W. Yeh, L. Harrington, A. Zai, K.P. Liao, and F. Dominici, 2017: Time-course of cause-specific hospital admissions during snowstorms: An analysis of electronic medical records from major hospitals in Boston, Massachusetts. *American Journal of Epidemiology*, **185** (4), 283-294. http://dx.doi.org/10.1093/aje/kww219

324. Fann, N., C.G. Nolte, P. Dolwick, T.L. Spero, A. Curry Brown, S. Phillips, and S. Anenberg, 2015: 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** (5), 570-580. http://dx.doi.org/10.1080/10962247.2014.996270

325. Stowell, J.D., Y.-m. Kim, Y. Gao, J.S. Fu, H.H. Chang, and Y. Liu, 2017: The impact of climate change and emissions control on future ozone levels: Implications for human health. *Environment International*, **108**, 41-50. http://dx.doi.org/10.1016/j.envint.2017.08.001

326. Wilson, A., B.J. Reich, C.G. Nolte, T.L. Spero, B. Hubbell, and A.G. Rappold, 2017: Climate change impacts on projections of excess mortality at 2030 using spatially varying ozone–temperature risk surfaces. *Journal of Exposure Science and Environmental Epidemiology*, **27**, 118-124. http://dx.doi.org/10.1038/jes.2016.14

327. EPA, 2017: Supplemental Information for Ozone Advance Areas Based On Pre-Existing National Modeling Analyses. U.S. EPA, Office of Air Quality Planning and Standards, Washington, DC, 7 pp. https://www.epa.gov/sites/production/files/2017-05/documents/national_modeling.advance.may_2017.pdf

328. Dreessen, J., J. Sullivan, and R. Delgado, 2016: Observations and impacts of transported Canadian wildfire smoke on ozone and aerosol air quality in the Maryland region on June 9–12, 2015. *Journal of the Air & Waste Management Association*, **66** (9), 842-862. http://dx.doi.org/10.1080/10962247.2016.1161674

329. Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M.A. Elder, W. Filley, J. Shropshire, L.B. Ford, C. Hedberg, P. Fleetwood, K.T. Hovanky, T. Kavanaugh, G. Fulford, R.F. Vrtis, J.A. Patz, J. Portnoy, F. Coates, L. Bielory, and D. Frenz, 2011: Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proceedings of the National Academy of Sciences of the United States of America*, **108** (10), 4248-4251. http://dx.doi.org/10.1073/pnas.1014107108

330. Ito, K., K.R. Weinberger, G.S. Robinson, P.E. Sheffield, R. Lall, R. Mathes, Z. Ross, P.L. Kinney, and T.D. Matte, 2015: The associations between daily spring pollen counts, over-the-counter allergy medication sales, and asthma syndrome emergency department visits in New York City, 2002-2012. *Environmental Health*, **14** (1), 71. http://dx.doi.org/10.1186/s12940-015-0057-0

331. IOM, 2011: *Climate Change, the Indoor Environment, and Health*. Institute of Medicine. The National Academies Press, Washington, DC, 286 pp. http://dx.doi.org/10.17226/13115

332. Park, J.-H., S.J. Cho, S.K. White, and J.M. Cox-Ganser, 2018: Changes in respiratory and non-respiratory symptoms in occupants of a large office building over a period of moisture damage remediation attempts. PLOS ONE, **13** (1), e0191165. http://dx.doi.org/10.1371/journal.pone.0191165

333. Rochlin, I., D.V. Ninivaggi, M.L. Hutchinson, and A. Farajollahi, 2013: Climate change and range expansion of the Asian tiger mosquito (*Aedes albopictus*) in northeastern USA: Implications for public health practitioners. PLOS ONE, **8** (4), e60874. http://dx.doi.org/10.1371/journal.pone.0060874

334. Johnson, B.J. and M.V.K. Sukhdeo, 2013: Drought-induced amplification of local and regional West Nile virus infection rates in New Jersey. *Journal of Medical Entomology*, **50** (1), 195-204. http://dx.doi.org/10.1603/me12035

335. Gobler, C.J., O.M. Doherty, T.K. Hattenrath-Lehmann, A.W. Griffith, Y. Kang, and R.W. Litaker, 2017: Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans. *Proceedings of the National Academy of Sciences of the United States of America*, **114** (19), 4975-4980. http://dx.doi.org/10.1073/pnas.1619575114

336. Jones, S., B. Schuster, J. Mahoney, J. Yu, C. Ellis, V. Cooper, and C. Whistler, 2011: The occurrence, abundance, phylogeny and virulence potential of pathogenic *Vibrio* species in New Hampshire shellfish waters. In *103rd Annual Meeting, National Shellfisheries Association* Baltimore, Maryland, March 27–31, 2011.

337. Newton, A.E., N. Garrett, S.G. Stroika, J.L. Halpin, M. Turnsek, and R.K. Mody, 2014: Notes from the field: Increase in *Vibrio parahaemolyticus* infections associated with consumption of Atlantic Coast shellfish—2013. *MMWR: Morbidity and Mortality Weekly Report*, **63** (15), 335-336. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6315a6.htm

338. Xu, F., S. Ilyas, J.A. Hall, S.H. Jones, V.S. Cooper, and C.A. Whistler, 2015: Genetic characterization of clinical and environmental *Vibrio parahaemolyticus* from the Northeast USA reveals emerging resident and non-indigenous pathogen lineages. *Frontiers in Microbiology*, **6** (272). http://dx.doi.org/10.3389/fmicb.2015.00272

339. EPA, 2004: Report to Congress: Impacts and Control of CSOs and SSOs. EPA 833-R-04-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. http://water.epa.gov/polwaste/npdes/cso/2004-Report-to-Congress.cfm

340. Soneja, S., C. Jiang, C. Romeo Upperman, R. Murtugudde, C. S. Mitchell, D. Blythe, A.R. Sapkota, and A. Sapkota, 2016: Extreme precipitation events and increased risk of campylobacteriosis in Maryland, U.S.A. *Environmental Research*, **149**, 216-221. http://dx.doi.org/10.1016/j.envres.2016.05.021

341. Jiang, C., K.S. Shaw, C.R. Upperman, D. Blythe, C. Mitchell, R. Murtugudde, A.R. Sapkota, and A. Sapkota, 2015: Climate change, extreme events and increased risk of salmonellosis in Maryland, USA: Evidence for coastal vulnerability. *Environment International*, **83**, 58-62. http://dx.doi.org/10.1016/j.envint.2015.06.006

342. DC Water, 2018: Clean Rivers Project [web site]. DC Water, Washington, DC. https://www.dcwater.com/clean-rivers-project

343. Ziska, L., A. Crimmins, A. Auclair, S. DeGrasse, J.F. Garofalo, A.S. Khan, I. Loladze, A.A. Pérez de León, A. Showler, J. Thurston, and I. Walls, 2016: Ch. 7: Food safety, nutrition, and distribution. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. U.S. Global Change Research Program, Washington, DC, 189–216. http://dx.doi.org/10.7930/J0ZP4417

344. Marx, M.A., C.V. Rodriguez, J. Greenko, D. Das, R. Heffernan, A.M. Karpati, F. Mostashari, S. Balter, M. Layton, and D. Weiss, 2006: Diarrheal illness detected through syndromic surveillance after a massive power outage: New York City, August 2003. *American Journal of Public Health*, **96** (3), 547-553. http://dx.doi.org/10.2105/ajph.2004.061358

345. Guenther, R. and J. Balbus, 2014: Primary Protection: Enhancing Health Care Resilience for a Changing Climate. U.S. Department of Health and Human Services. https://toolkit.climate.gov/sites/default/files/SCRHCFI%20Best%20Practices%20Report%20final2%202014%20Web.pdf

346. Hampson, A., T. Bourgeois, G. Dillingham, and I. Panzarella, 2013: Combined Heat and Power: Enabling Resilient Energy Infrastructure for Critical Facilities. ORNL/TM-2013/100. ICF International, Washington, DC, 41 pp. https://www.energy.gov/sites/prod/files/2013/11/f4/chp_critical_facilities.pdf

347. Di Liberto, T., 2016: "'Thousand-year' downpour led to deadly West Virginia floods." *Climate.gov News & Features*, July 8. National Oceanic and Atmospheric Administration, Silver Spring, MD. https://www.climate.gov/news-features/event-tracker/thousand-year-downpour-led-deadly-west-virginia-floods

348. Rhodes, J. and R. Gupta, 2016: Building resilient communities: Preparedness and response for health care and public health professionals. *West Virginia Medical Journal*, **112** (5), 24-25. http://digital.graphcompubs.com/publication/?i=336725

349. Lieberman-Cribbin, W., B. Liu, S. Schneider, R. Schwartz, and E. Taioli, 2017: Self-reported and FEMA flood exposure assessment after Hurricane Sandy: Association with mental health outcomes. *PLOS ONE*, **12** (1), e0170965. http://dx.doi.org/10.1371/journal.pone.0170965

350. Noelke, C., M. McGovern, D.J. Corsi, M.P. Jimenez, A. Stern, I.S. Wing, and L. Berkman, 2016: Increasing ambient temperature reduces emotional well-being. *Environmental Research*, **151**, 124-129. http://dx.doi.org/10.1016/j.envres.2016.06.045

351. Trombley, J., S. Chalupka, and L. Anderko, 2017: Climate change and mental health. *AJN The American Journal of Nursing*, **117** (4), 44-52. http://dx.doi.org/10.1097/01.NAJ.0000515232.51795.fa

352. Schmeltz, M.T. and J.L. Gamble, 2017: Risk characterization of hospitalizations for mental illness and/or behavioral disorders with concurrent heat-related illness. *PLOS ONE*, **12** (10), e0186509. http://dx.doi.org/10.1371/journal.pone.0186509

353. Zimmerman, C., L. Kiss, and M. Hossain, 2011: Migration and health: A framework for 21st century policy-making. *PLOS Medicine*, **8** (5), e1001034. http://dx.doi.org/10.1371/journal.pmed.1001034

354. Balbus, J., A. Crimmins, J.L. Gamble, D.R. Easterling, K.E. Kunkel, S. Saha, and M.C. Sarofim, 2016: Ch. 1: Introduction: Climate change and human health. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. U.S. Global Change Research Program, Washington, DC, 25–42. http://dx.doi.org/10.7930/J0VX0DFW

355. Massachusetts CZM, 2018: StormSmart Coasts Program [web site]. Massachusetts Office of Coastal Zone Management (CZM). https://www.mass.gov/stormsmart-coasts-program