Climate Change Impacts in the United States

CHAPTER 16 NORTHEAST

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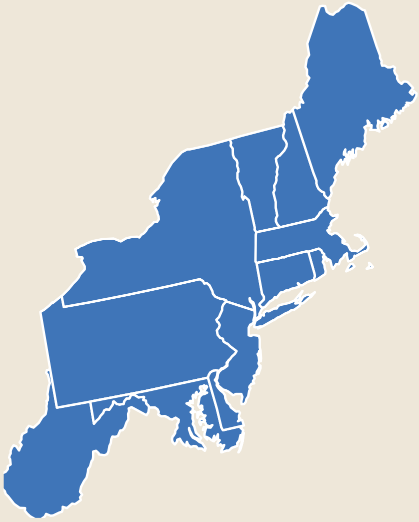

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16 NORTHEAST

Key Messages

1. **Heat waves, coastal flooding, and river flooding will pose a growing challenge to the region's environmental, social, and economic systems. This will increase the vulnerability of the region's residents, especially its most disadvantaged populations.**

2. **Infrastructure will be increasingly compromised by climate-related hazards, including sea level rise, coastal flooding, and intense precipitation events.**

3. **Agriculture, fisheries, and ecosystems will be increasingly compromised over the next century by climate change impacts. Farmers can explore new crop options, but these adaptations are not cost- or risk-free. Moreover, adaptive capacity, which varies throughout the region, could be overwhelmed by a changing climate.**

4. **While a majority of states and a rapidly growing number of municipalities have begun to incorporate the risk of climate change into their planning activities, implementation of adaptation measures is still at early stages.**

Sixty-four million people are concentrated in the Northeast. The high-density urban coastal corridor from Washington, D.C., north to Boston is one of the most developed environments in the world. It contains a massive, complex, and long-standing network of supporting infrastructure. The region is home to one of the world's leading financial centers, the nation's capital, and many defining cultural and historical landmarks.

The region has a vital rural component as well. The Northeast includes large expanses of sparsely populated but ecologically and agriculturally important areas. Much of the Northeast landscape is dominated by forest, but the region also has grasslands, coastal zones, beaches and dunes, and wetlands, and it is known for its rich marine and freshwater fisheries. These natural areas are essential to recreation and tourism sectors and support jobs through the sale of timber, maple syrup, and seafood. They also contribute important ecosystem services to broader populations – protecting water supplies, buffering shorelines, and sequestering carbon in soils and vegetation. The twelve Northeastern states have more than 180,000 farms, with $17 billion in annual sales.[1] The region's ecosystems and agricultural systems are tightly interwoven, and both are vulnerable to a changing climate.

Although urban and rural regions in the Northeast have profoundly different built and natural environments, both include populations that have been shown to be highly vulnerable to climate hazards and other stresses. Both also depend on aging infrastructure that has already been stressed by climate hazards including heat waves, as well as coastal and riverine flooding due to a combination of sea level rise, storm surge, and extreme precipitation events.

The Northeast is characterized by a diverse climate.[2] Average temperatures in the Northeast generally decrease to the north, with distance from the coast, and at higher elevations. Average annual precipitation varies by about 20 inches throughout the Northeast with the highest amounts observed in coastal and select mountainous regions. During winter, frequent storms bring bitter cold and frozen precipitation, especially to the north. Summers are warm and humid, especially to the south. The Northeast is often affected by extreme events such as ice storms, floods, droughts, heat waves, hurricanes, and major storms in the Atlantic Ocean off the northeast coast, referred to as nor'easters. However, variability is large in both space and

time. For example, parts of southern New England that experienced heavy snows in the cold season of 2010-2011 experienced little snow during the cold season of 2011-2012. Of course, even a season with low totals can feature costly extreme events; snowfall during a 2011 pre-Halloween storm that hit most of the Northeast, when many trees were still in leaf, knocked out power for up to 10 days for thousands of households.

Observed Climate Change

Between 1895 and 2011, temperatures in the Northeast increased by almost 2˚F (0.16˚F per decade), and precipitation increased by approximately five inches, or more than 10% (0.4 inches per decade).[3] Coastal flooding has increased due to a rise in sea level of approximately 1 foot since 1900. This rate of sea level rise exceeds the global average of approximately 8 inches (see Ch. 2: Our Changing Climate, Key Message 10; Ch. 25: Coasts), due primarily to land subsidence,[4] although recent research suggests that changes in ocean circulation in the North Atlantic – specifically, a weakening of the Gulf Stream – may also play a role.[5]

The Northeast has experienced a greater recent increase in extreme precipitation than any other region in the United States; between 1958 and 2010, the Northeast saw more than a 70% increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) (see Ch. 2: Our Changing Climate, Figure 2.18).[7]

Sea Level is Rising

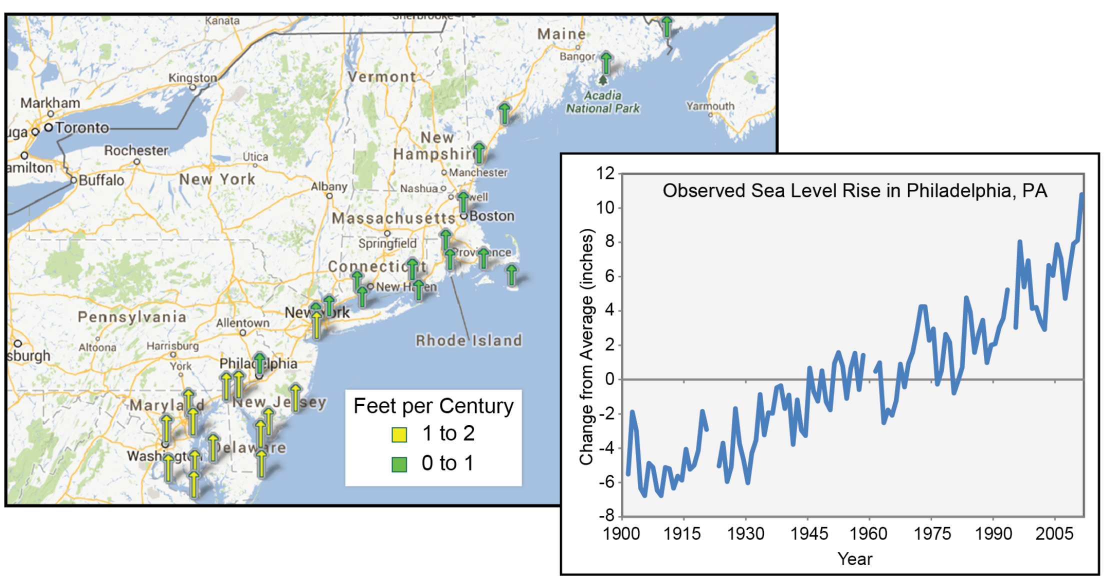


Figure 16.1. (Map) Local sea level trends in the Northeast region. Length of time series for each arrow varies by tide gauge location. (Figure source: NOAA[6]). (Graph) Observed sea level rise in Philadelphia, PA, has significantly exceeded the global average of 8 inches over the past century, increasing the risk of impacts to critical urban infrastructure in low-lying areas. Over 100 years (1901-2012), sea level increased 1.2 feet (Data from Permanent Service for Mean Sea Level).

Projected Climate Change

As in other areas, the amount of warming in the Northeast will be highly dependent on global emissions of heat-trapping gases. If emissions continue to increase (as in the A2 scenario), warming of 4.5F° to 10°F is projected by the 2080s; if global emissions were reduced substantially (as in the B1 scenario), projected warming ranges from about 3°F to 6°F by the 2080s.[3]

Under both emissions scenarios, the frequency, intensity, and duration of heat waves is expected to increase, with larger increases under higher emissions (Ch. 2: Our Changing Climate). Much of the southern portion of the region, including the majority of Maryland and Delaware, and southwestern West Virginia and New Jersey, are projected by mid-century to experience many more days per year above 90°F compared to the end of last century under continued increases in emissions (Figure 16.2, A2 scenario). This will affect the region's vulnerable populations, infrastructure, agriculture, and ecosystems.

The frequency, intensity, and duration of cold air outbreaks is expected to decrease as the century progresses, although some research suggests that loss of Arctic sea ice could indirectly reduce this trend by modifying the jet stream and mid-latitude weather patterns.[8,9]

Projections of precipitation changes are less certain than projections of temperature increases.[3] Winter and spring precipitation is projected to increase, especially but not exclusively in the northern part of the region (Ch. 2: Our Changing Climate, Key Messages 5 and 6).[3,10] A range of model projections for the end of this century under a higher emissions scenario (A2), averaged over the region, suggests about 5% to 20% (25th to 75th percentile of model projections) increases in winter precipitation. Projected changes in summer and fall, and for the entire year, are generally small at the end of the century compared to natural variations (Ch. 2: Our Changing Climate, Key Message 5).[3] The frequency of heavy downpours is projected to continue to increase as the century progresses (Ch. 2: Our Changing Climate, Key Message 6). Seasonal drought risk is also projected to increase in summer and fall as higher temperatures lead to greater evaporation and earlier winter and spring snowmelt.[11]

Global sea levels are projected to rise 1 to 4 feet by 2100 (Ch. 2: Our Changing Climate, Key Message 10),[12] depending in large part on the extent to which the Greenland and West Antarctic Ice Sheets experience significant melting. Sea level rise along most of the coastal Northeast is expected to exceed the global average rise due to local land subsidence, with the possibility of even greater regional sea level rise if the Gulf Stream weakens as some models suggest.[5,13] Sea level rise of two feet, without any changes in storms, would more than triple the frequency of dangerous coastal flooding throughout most of the Northeast.[14]

Although individual hurricanes cannot be directly attributed to climate change, Hurricanes Irene and Sandy nevertheless provided "teachable moments" by demonstrating the region's vulnerability to extreme weather events and the potential for adaptation to reduce impacts.

Projected Increases in the Number of Days over 90°F

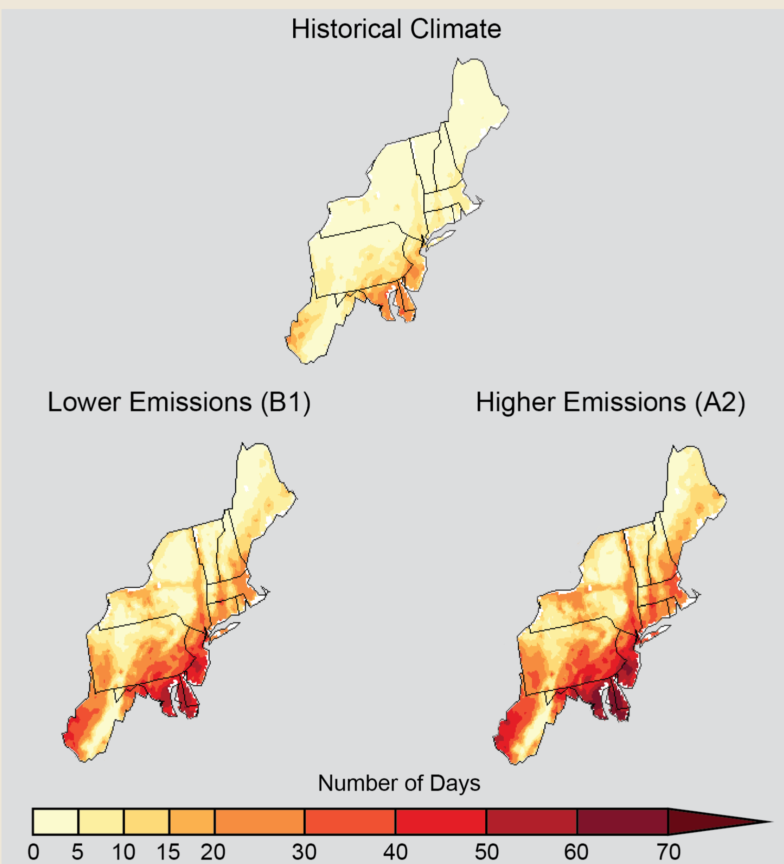


Figure 16.2. Projected number of days per year with a maximum temperature greater than 90°F averaged between 2041 and 2070, compared to 1971-2000 (Historical Climate), assuming continued increases in global emissions (A2) and substantial reductions in future emissions (B1). (Figure source: NOAA NCDC / CICS-NC).

Hurricane vulnerability

Two recent events contrast existing vulnerability to extreme events: Hurricane Irene, which produced a broad swath of very heavy rain (greater than five inches in total and sometimes two to three inches per hour in some locations) from southern Maryland to northern Vermont from August 27 to 29, 2011; and Hurricane Sandy, which caused massive coastal damage from storm surge and flooding along the Northeast coast from October 28 to 30, 2012.

Rainfall associated with Irene led to hydrological extremes in the region. These heavy rains were part of a broader pattern of wet weather preceding the storm (rainfall totals for August and September exceeded 25 inches across much of the Northeast) that left the region predisposed to extreme flooding from Irene; for example, the Schoharie Creek in New York experienced a 500-year flood.[15]

In anticipation of Irene, the New York City mass transit system was shut down, and 2.3 million coastal residents in Delaware, New Jersey, and New York faced mandatory evacuations. However, it was the inland impacts, especially in upstate New York and in central and southern Vermont, that were most severe. Ironically, many New York City residents fled to inland locations, which were harder hit. Flash flooding washed out roads and bridges, undermined railroads, brought down trees and power lines, flooded homes and businesses, and damaged floodplain forests. In Vermont, more than 500 miles of roadways and approximately 200 bridges were damaged, with estimated rebuilding costs of $175 to $250 million. Hazardous wastes were released in a number of areas, and 17 municipal wastewater treatment plants were breached by floodwaters. Agricultural losses included damage to barn structures and flooded fields of crops. Many towns and villages were isolated for days due to infrastructure impacts from river flooding (see also Ch. 5: Transportation, "Tropical Storm Irene Devastates Vermont Transportation in August 2011").[2] Affected residents suffered from increased allergen exposure due to mold growth in flooded homes and other structures and were exposed to potentially harmful chemicals and pathogens in their drinking water. In the state of Vermont, cleaning up spills from aboveground hazardous waste tanks cost an estimated $1.75 million. Septic systems were also damaged from high groundwater levels and river or stream erosion, including 17 septic system failures in the state of Vermont.[17]

Flooding and Hurricane Irene

Figure 16.3. Hurricane Irene over the Northeast on August 28, 2011. The storm, which brought catastrophic flooding rains to parts of the Northeast, took 41 lives in the United States, and the economic cost was estimated at $16 billion.[16] (Figure source: MODIS instrument on NASA's Aqua satellite).

Sandy was responsible for about 150 deaths, approximately half of which occurred in the Northeast.[18] Damages, concentrated in New Jersey, New York, and Connecticut, were estimated at $60 to $80 billion, making Sandy the second most costly Atlantic Hurricane in history behind Katrina.[19] It is also estimated that 650,000 homes were damaged or destroyed, and that 8.5 million people were without power.[18] Floodwaters inundated subway tunnels in New York City (see also Ch. 5: Transportation, "Hurricane Sandy"). Sandy also caused significant damage to the electrical grid and overwhelmed sewage treatment plants.[18] In New Jersey, repairs to damaged power and gas lines are expected to cost about $1 billion, and repairs to waste, water, and sewer systems are expected to cost $3 billion.

Many of these vulnerabilities to coastal flooding and sea level rise (Ch. 2: Our Changing Climate, Key Message 10) and intensifying storms (Ch. 2: Our Changing Climate, Key Messages 8 and 9) – including the projected frequency of flooding of tunnels and airports – were documented as early as 2001 in a report developed in support of the 2000 National Climate Assessment.[20] Despite such reports, the observed vulnerability was a surprise to many coastal residents, which suggests improved communication is needed.

Continued

Hurricane vulnerability

Over the last decade, cities, states, and agencies in the New York metropolitan region took steps to reduce their vulnerability to coastal storms.[21] In 2008, New York City convened a scientific body of experts – the New York City Panel on Climate Change (NPCC) – and formed a Climate Adaptation Task Force comprised of approximately 40 agencies, private sector companies, and regional groups. A process, approach, and tools for climate change adaptation were developed and documented in New York City[11,22] and New York State.[23] In 2012, the NPCC and Climate Adaptation Task Force were codified into New York City law, a key step towards institutionalizing climate science, impact, and adaptation assessment into long-term planning.[24]

These initiatives led to adaptation efforts, including elevating infrastructure, restoring green spaces, and developing evacuation plans that helped reduce damage and save lives during Irene and Sandy (also see discussion of Hurricane Sandy in Ch. 11: Urban). As rebuilding and recovery advances,[24] decision-making based on current and projected risks from such events by a full set of stakeholders and participants in the entire Northeast could dramatically improve resilience across the region.

Coastal Flooding Along New Jersey's Shore

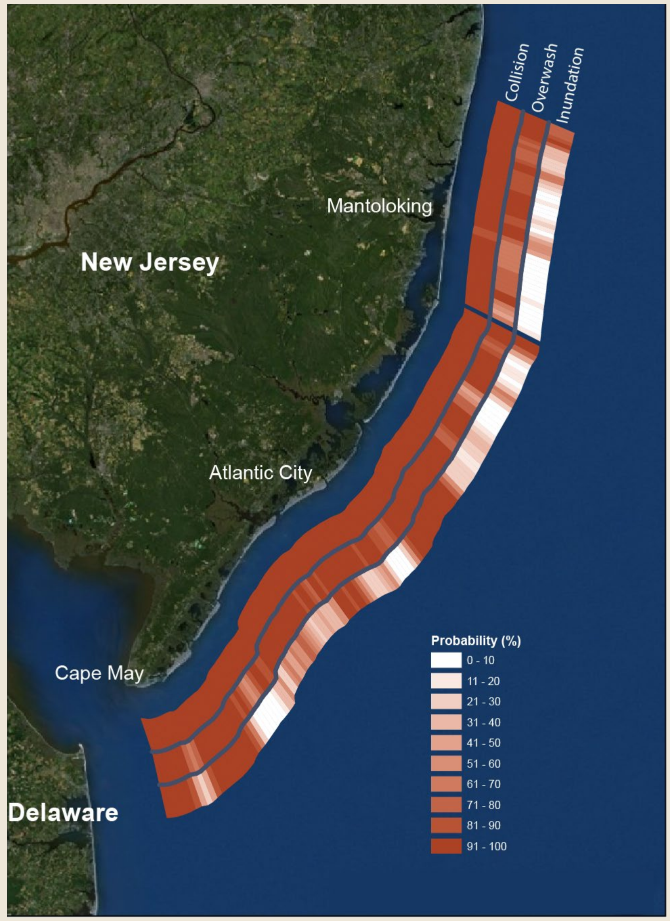


Figure 16.4. Predictions of coastal erosion prior to Sandy's arrival provided the region's residents and decision-makers with advance warning of potential vulnerability. The map shows three bands: collision of waves with beaches causing erosion on the front of the beach; overwash that occurs when water reaches over the highest point and erodes from the rear, which carries sand inland; and inundation, when the shore is severely eroded and new channels can form that lead to permanent flooding. The probabilities are based on the storm striking at high tide. For New Jersey, the model estimated that 21% of the shoreline had more than a 90% chance of experiencing inundation. These projections were realized, and made the New Jersey coastline even more vulnerable to the nor'easter that followed Hurricane Sandy by only 10 days. (Figure source: ESRI and USGS 2012[25]).

Key Message 1: Climate Risks to People

Heat waves, coastal flooding, and river flooding will pose a growing challenge to the region's environmental, social, and economic systems. This will increase the vulnerability of the region's residents, especially its most disadvantaged populations.

Urban residents have unique and multifaceted vulnerabilities to heat extremes. Northeastern cities, with their abundance of concrete and asphalt and relative lack of vegetation, tend to have higher temperatures than surrounding regions (the "urban heat island" effect). During extreme heat events, nighttime temperatures in the region's big cities are generally several degrees higher[26] than surrounding regions, leading to increased heat-related death among those less able to recover from the heat of the day.[27] Since the hottest days in the Northeast are often associated with high concentrations of ground-level ozone and other pollutants,[28] the combination of heat stress and poor air quality can pose a major health risk to vulnerable groups: young children, the elderly, and those with pre-existing health conditions including asthma.[29] Vulnerability is further increased as key infrastructure, including electricity for potentially life-saving air conditioning, is more likely to fail precisely when it is most needed – when demand exceeds available supply. Significant investments may be required to ensure that power generation keeps up with rising demand associated with rising temperatures.[30] Finally, vulnerability to heat waves is not evenly distributed throughout urban areas; outdoor versus indoor air temperatures, air quality, baseline health, and access to air conditioning are all dependent on socioeconomic factors.[29] Socioeconomic factors that tend to increase vulnerability to such hazards include race and ethnicity (being a minority), age (the elderly and children), gender (female), socioeconomic status (low income, status, or poverty), and education (low educational attainment). The condition of human settlements (type of housing and construction, infrastructure, and access to lifelines) and the built environment are also important determinants of socioeconomic vulnerability, especially given the fact that these characteristics influence potential economic losses, injuries, and mortality.[31]

Urban Heat Island

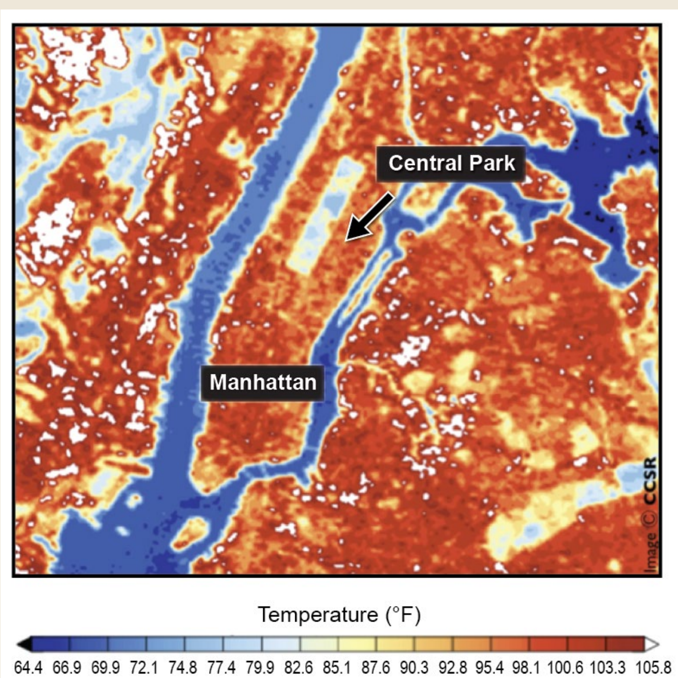


Figure 16.5. Surface temperatures in New York City on a summer's day show the "urban heat island," with temperatures in populous urban areas being approximately 10°F higher than the forested parts of Central Park. Dark blue reflects the colder waters of the Hudson and East Rivers. (Figure source: Center for Climate Systems Research, Columbia University).

Increased health-related impacts and costs, such as premature death and hospitalization due to even modest increases in heat, are predicted in the Northeast's urban centers (Ch. 9: Human Health).[32] One recent study projected that temperature changes alone would lead to a 50% to 91% increase in heat-related deaths in Manhattan by the 2080s (relative to a 1980s baseline).[33] Increased ground-level ozone due to warming is projected to increase emergency department visits for ozone-related asthma in children (0 to 17 years of age) by 7.3% by the 2020s (given the A2 scenario) relative to a 1990 baseline of approximately 650 visits in the New York metropolitan area.[34]

Heat wave research has tended to focus on urban areas, but vulnerability to heat may also become a major issue in rural areas and small towns because air conditioning is currently not prevalent in parts of the rural Northeast where heat waves have historically been rare. Some areas of northern New England, near the Canadian border, are projected to shift from having less than five to more than 15 days per year over 90°F by the 2050s under the higher emissions scenario (A2) of heat-trapping gases.[3] It should be noted that winter heating needs, a significant expense for many Northeastern residents, are likely to decrease as the century progresses.[35]

The impacts of climate change on public health will extend beyond the direct effects of temperature on human physiology. Changing distributions of temperature, precipitation, and carbon dioxide could affect the potency of plant allergens,[36] and there has been an observed increase of 13 to 27 days in the ragweed pollen season at latitudes above 44°N.[36]

Vector-borne diseases are an additional concern. Most occurrences of Lyme disease in United States are in the Northeast, especially Connecticut.[37] While it is unclear how climate change will impact Lyme disease,[38] several studies in the Northeast have linked tick activity and Lyme disease incidence to climate, specifically abundant late spring and early summer moisture.[39] West Nile Virus (WNV) is another vector-borne disease that may be influenced by changes in climate. Suitable habitat for the Asian Tiger Mosquito, which can transmit West Nile and other vector-borne diseases, is expected to increase in the Northeast from the current 5% to 16% in the next two decades and from 43% to 49% by the end of the century, exposing more than 30 million people to the threat of dense infestations by this species.[40]

Many Northeast cities, including New York, Boston, and Philadelphia, are served by combined sewer systems that collect and treat both stormwater and municipal wastewater. During heavy rain events, combined systems can be overwhelmed and untreated water may be released into local water bodies. In Connecticut, the risk for contracting a stomach illness while swimming significantly increased after a one inch precipitation event,[41] and studies have found associations between diarrheal illness among children and sewage discharge in Milwaukee.[42] More frequent heavy rain events could therefore increase the incidence of waterborne disease.

Historical settlement patterns and ongoing investment in coastal areas and along major rivers combine to increase the vulnerabilities of people in the Northeast to sea level rise and coastal storms. Of the Northeast's population of 64 million,[43] approximately 1.6 million people live within the Federal Emergency Management Agency's (FEMA) 100-year coastal flood zone, with the majority – 63% of those at risk – residing in New York and New Jersey.[44] As sea levels rise, populations in the current 1-in-100-year coastal flood zone (defined as the area with at least a 1% chance of experiencing a coastal flood in a given year) will experience more frequent flooding, and populations that have historically fallen outside the 1-in-100-year flood zone will find themselves in that zone. People living in coastal flood zones are vulnerable to direct loss of life and injury associated with tropical storms and nor'easters. Flood damage to personal property, businesses, and public infrastructure can also result (see Key Message 2).

This risk is not limited to the 1-in-100-year flood zone; in the Mid-Atlantic part of the region alone, estimates suggest that between 450,000 and 2.3 million people are at risk from a three foot sea level rise,[45] which is in the range of projections for this century.

Throughout the Northeast, populations are also concentrated along rivers and their flood plains. In mountainous regions, including much of West Virginia and large parts of Pennsylvania, New York, Vermont, and New Hampshire, more intense precipitation events (Ch. 2: Our Changing Climate)[3] will mean greater flood risk, particularly in valleys, where people, infrastructure, and agriculture tend to be concentrated.

Key Message 2: Stressed Infrastructure

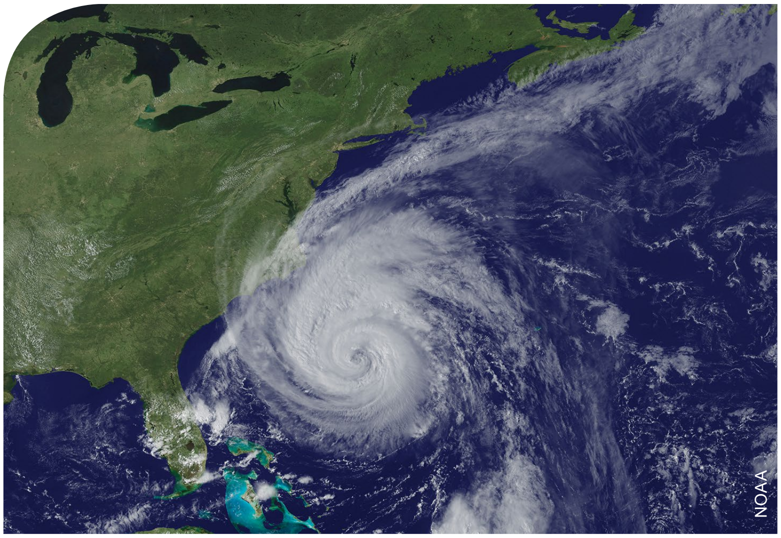
Infrastructure will be increasingly compromised by climate-related hazards, including sea level rise, coastal flooding, and intense precipitation events.

Disruptions to services provided by public and private infrastructure in the Northeast both interrupt commerce and threaten public health and safety (see also Ch. 11: Urban).[46] In New York State, two feet of sea level rise is estimated (absent adaptation investment) to flood or render unusable 212 miles of roads, 77 miles of rail, 3,647 acres of airport facilities, and 539 acres of runways.[47] Port facilities, such as in Maryland (primarily Baltimore), also have flooding impact estimates: 298 acres, or 32% of the overall port facilities in the state.[47] These impacts have potentially significant economic ramifications. For example, in 2006 alone the Port of Baltimore generated more than 50,200 jobs, $3.6 billion in personal income, $1.9 billion in business revenues, and $388 million in state, county, and municipal tax.[48] The New York City Panel on Climate Change highlighted a broader range of climate impacts on infrastructure sectors (see Table 16.1).[11] Although this study focused specifically on New York City, these impacts are applicable throughout the region. Predicted impacts of coastal flooding on infrastructure were largely borne out by Hurricane Sandy; sea level rise will only increase these vulnerabilities.

The more southern states within the region, including Delaware and Maryland, have a highly vulnerable land area because of a higher rate of sea level rise and relatively flat coastlines compared to the northern tier. The northern states, including Massachusetts, Rhode Island, and Connecticut, have less land area exposed to a high inundation risk because of a lower relative sea level rise and because of their relatively steep coastal terrain.[49] Still, low-lying coastal metropolitan areas in New England have considerable infrastructure at risk. In Boston alone, cumulative damage to buildings and building contents, as well as the associated emergency costs, could potentially be as high as $94 billion between 2000 and 2100, depending on the sea level rise scenario and which adaptive actions are taken.[50]

Table 16.1. Impacts of sea level rise and coastal floods on critical coastal infrastructure by sector. Sources: Horton and Rosenzweig 2010,[51] Zimmerman and Faris 2010,[52] and Ch. 25: Coasts.

Communications	Energy	Transportation	Water and Waste
Higher average sea level			
• Increased saltwater encroachment and damage to low-lying communications infrastructure not built to withstand saltwater exposure • Increased rates of coastal erosion and/or permanent inundation of low-lying areas, causing increased maintenance costs and shortened replacement cycles • Cellular tower destruction or loss of function	• Increased coastal erosion rates and/or permanent inundation of low-lying areas, threatening coastal power plants • Increased equipment damage from corrosive effects of saltwater encroachment, resulting in higher maintenance costs and shorter replacement cycles	• Increased saltwater encroachment and damage to infrastructure not built to withstand saltwater exposure • Increased coastal erosion rates and/or permanent inundation of low-lying areas, resulting in increased maintenance costs and shorter replacement cycles • Decreased clearance levels under bridges	• Increased saltwater encroachment and damage to water and waste infrastructure not built to withstand saltwater exposure • Increased release of pollution and contaminant runoff from sewer systems, treatment plants, brownfields, and waste storage facilities • Permanent inundation of low-lying areas, wetlands, piers, and marine transfer stations • Increased saltwater infiltration into freshwater distribution systems
More frequent and intense coastal flooding			
• Increased need for emergency management actions with high demand on communications infrastructure • Increased damage to communications equipment and infrastructure in low-lying areas	• Increased need for emergency management actions • Exacerbated flooding of low-lying power plants and equipment, as well as structural damage to infrastructure due to wave action • Increased use of energy to control floodwaters • Increased number and duration of local outages due to flooded and corroded equipment	• Increased need for emergency management actions • Exacerbated flooding of streets, subways, tunnel and bridge entrances, as well as structural damage to infrastructure due to wave action • Decreased levels of service from flooded roadways; increased hours of delay from congestion during street flooding episodes • Increased energy use for pumping	• Increased need for emergency management actions • Exacerbated street, basement, and sewer flooding, leading to structural damage to infrastructure • Episodic inundation of low-lying areas, wetlands, piers, and marine transfer stations



Coney Island after Hurricane Irene

Figure 16.6. Flooded subway tracks in Coney Island after Hurricane Irene. (Photo credit: Metropolitan Transportation Authority of the State of New York 2011).

In the transportation sector (see also Ch. 5: Transportation), many of the region's key highways (including I-95) and rail systems (including Amtrak and commuter rail networks) span areas that are prone to coastal flooding. In addition to temporary service disruptions, storm surge flooding can severely undermine or disable critical infrastructure along coasts, including subway systems, wastewater treatment plants, and electrical substations. Saltwater corrosion can damage sensitive and critical electrical equipment, such as electrical substations for energy distribution and signal equipment for rail systems; corrosion also accelerates rust damage on rail lines. Saltwater also threatens groundwater supplies and damages wastewater treatment plants.

Key Message 3: Agricultural and Ecosystem Impacts

Agriculture, fisheries, and ecosystems will be increasingly compromised over the next century by climate change impacts. Farmers can explore new crop options, but these adaptations are not cost- or risk-free. Moreover, adaptive capacity, which varies throughout the region, could be overwhelmed by a changing climate.

Farmers in the Northeast are already experiencing consequences of climate change. In addition to direct crop damage from increasingly intense precipitation events, wet springs can delay planting for grain and vegetables in New York, for example, and subsequently delay harvest dates and reduce yields.[53] This is an issue for agriculture nationally,[54] but is particularly acute for the Northeast, where heavy rainfall events have increased more than in any other region of the country (Ch. 2: Our Changing Climate, Key Message 6).[7] In the future, farmers may also face too little water in summer to meet increased crop water demand as summers become hotter and growing seasons lengthen.[55,56] Increased frequency of summer heat stress is also projected, which can negatively affect crop yields and milk production.[57]

Despite a trend toward warmer winters, the risk of frost and freeze damage continues, and has paradoxically increased over the past decade (see also Ch. 8: Ecosystems). These risks are exacerbated for perennial crops in years with variable winter temperatures. For example, midwinter-freeze damage cost wine grape growers in the Finger Lakes region of New York millions of dollars in losses in the winters of 2003 and 2004.[58] This was likely due to de-hardening of the vines during an unusually warm December, which increased susceptibility to cold damage just prior to a subsequent hard freeze. Another avenue for cold damage, even in a relatively warm winter, is when there is an extended warm period in late winter or early spring causing premature leaf-out or bloom, followed by a damaging frost event, as occurred throughout the Northeast in 2007[59] and again in 2012 when apple, grape, cherry, and other fruit crops were hard hit.[60]

Increased weed and pest pressure associated with longer growing seasons and warmer winters will be an increasingly important challenge; there are already examples of earlier arrival and increased populations of some insect pests such as corn earworm.[57] Furthermore, many of the most aggressive weeds, such as kudzu, benefit more than crop plants from higher atmospheric carbon dioxide, and become more resistant to herbicide control.[61] Many weeds respond better than most cash crops to increasing carbon dioxide concentrations, particularly "invasive" weeds with the so-called C_3 photosynthetic pathway, and with rapid and expansive growth patterns, including large allocations of below-ground biomass, such as roots.[62] Research also suggests that glyphosate (for example, Roundup), the most widely-used herbicide in the United States, loses its efficacy on weeds grown at the increased carbon dioxide levels likely to occur in the coming decades.[63] To date, all weed/crop competition studies where the photosynthetic pathway is the same for both species favor weed growth over crop growth as carbon dioxide is increased.[61]

Effects of rising temperatures on the Northeast's ecosystems have already been clearly observed (see also Ch. 8: Ecosystems). Further, changes in species distribution by elevation are occurring; a Vermont study found an upslope shift of 299 to 390 feet in the boundary between northern hardwoods and boreal forest on the western slopes of the Green Mountains between 1964 and 2004.[64] Wildflowers[65] and woody perennials are blooming earlier [66] and migratory birds are arriving sooner.[67] Because species differ in their ability to adjust, asynchronies (like a mismatch between key food source availability and migration patterns) can develop, increasing species and ecosystem vulnerability. Several bird species have expanded their ranges northward[68] as have some invasive insect species, such as the hemlock woolly adelgid,[69] which has devastated hemlock trees. Warmer winters and less snow cover in recent years have contributed to increased deer populations[70] that degrade forest understory vegetation.[71]

As ocean temperatures continue to rise, the range of suitable habitat for many commercially important fish and shellfish species is projected to shift northward. For example, cod and lobster fisheries south of Cape Cod are projected to have significant declines.[72] Although suitable habitats will be shrinking for some species (such as coldwater fish like brook trout) and expanding for others (such as warmwater fish like bass), it is difficult to predict what proportion of species will be able to move or adapt as their optimum climate zones shift.[73] As each species responds uniquely to climate change, disruptions of important species interactions (plants and pollinators; predators and prey) can be expected. For example, it is uncertain what forms of vegetation will move into the Adirondack Mountains when the suitable habitat for spruce-fir forests disappears.[74] Increased productivity of some northern hardwood trees in the Northeast is projected (due to longer growing seasons and assuming a significant benefit from higher atmospheric carbon dioxide), but summer drought and other extreme events may offset potential productivity increases.[75] Range shifts in traditional foods gathered from the forests by Native American communities, such as Wabanaki berries in the Northeast, can have negative health and cultural impacts (Ch. 12: Indigenous Peoples).[76]

In contrast, many insect pests, pathogens, and invasive plants like kudzu appear to be highly and positively responsive to recent and projected climate change.[77] Their expansion will lead to an overall loss of biodiversity, function, and resilience of some ecosystems.

The Northeast's coastal ecosystems and the species that inhabit them are highly vulnerable to rising seas (see also Ch. 25: Coasts, Key Message 4). Beach and dune erosion, both a cause and effect of coastal flooding, is also a major issue in the Northeast.[78,79] Since the early 1800s, there has been an estimated 39% decrease in marsh coverage in coastal New England; in the metropolitan Boston area, marsh coverage is estimated to be less than 20% of its late 1700s value.[80] Impervious urban surfaces and coastal barriers such as seawalls limit the ability of marshes to expand inland as sea levels rise.[81]

The Chesapeake Bay

The Chesapeake Bay is the largest U.S. estuary, with a drainage basin that extends over six states. It is a critical and highly integrated natural and economic system threatened by changing land-use patterns and a changing climate – including sea level rise, higher temperatures, and more intense precipitation events. The ecosystem has a central role in the economy, including providing sources of food for people and the region's other inhabitants, and cooling water for the energy sector. It also provides critical ecosystem services.

As sea levels rise, the Chesapeake Bay region is expected to experience an increase in coastal flooding and drowning of estuarine wetlands. The lower Chesapeake Bay is especially at risk due to high rates of sinking land (known as subsidence).[82] Climate change and sea level rise are also likely to cause a number of ecological impacts, including declining water quality and clarity, increases in harmful algae and low oxygen (hypoxia) events, decreases in a number of species including eelgrass and seagrass beds, and changing interactions among trophic levels (positions in the food chain) leading to an increase in subtropical fish and shellfish species in the bay.[83]

Key Message 4: Planning and Adaptation

While a majority of states and a rapidly growing number of municipalities have begun to incorporate the risk of climate change into their planning activities, implementation of adaptation measures is still at early stages.

Of the 12 states in the Northeast, 11 have developed adaptation plans for several sectors and 10 have released, or plan to release, statewide adaptation plans.[84] Given the interconnectedness of climate change impacts and adaptation, multi-state coordination could help to ensure that information is shared efficiently and that emissions reduction and adaptation strategies do not operate at cross-purposes.

Connecticut Coastline and Expanding Salt Marshes

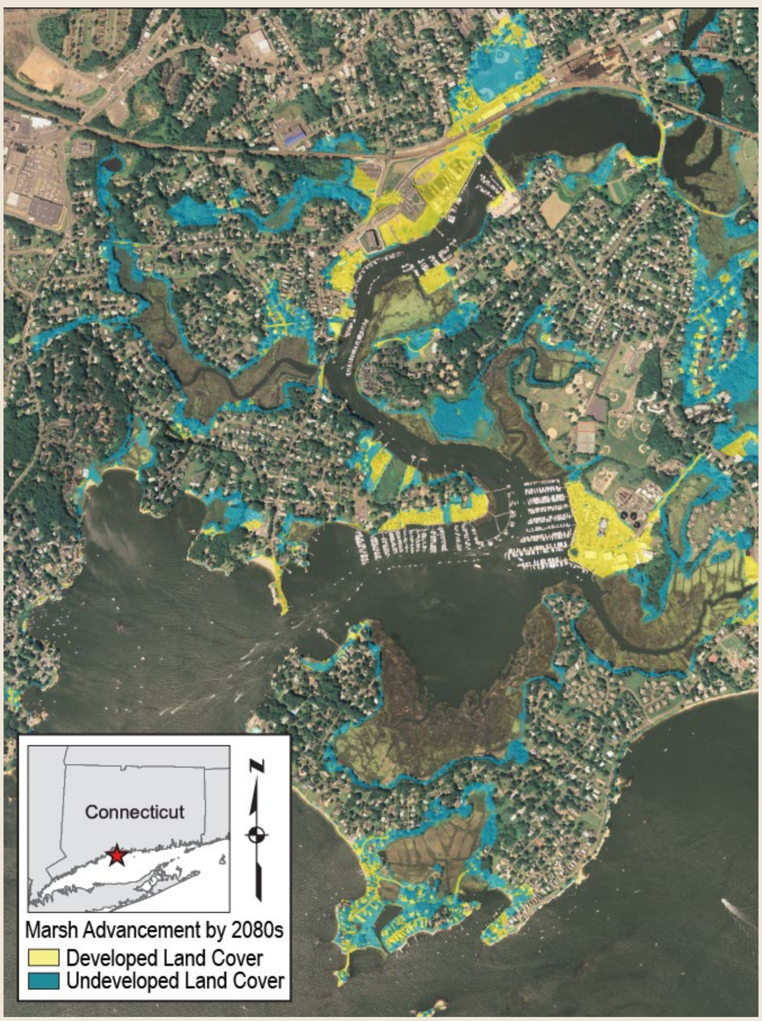


Figure 16.7. The Nature Conservancy's adaptation decision-support tool (www.coastalresilience.org)[88] depicts building-level impacts due to inundation (developed land cover, yellow areas) and potential marsh advancement zones (undeveloped land cover – currently forest, grass, and agriculture – blue areas) using downscaled sea level rise projections (52 inches by 2080s depicted) along the Connecticut and New York coasts. (Figure source: Ferdaña et al. 2010,[90] Beck et al. 2013[89]).

Local and state governments in the Northeast have been leaders and incubators in utilizing legal and regulatory opportunities to foster climate change policies.[85] The Regional Greenhouse Gas Initiative (RGGI) was the first market-based regulatory program in the U.S. aimed at reducing greenhouse gas emissions; it is a cooperative effort among nine northeastern states.[86] Massachusetts became the first state to officially incorporate climate change impacts into its environmental review procedures by adopting legislation that directs agencies to "consider reasonably foreseeable climate change impacts, including additional greenhouse gas emissions, and effects, such as predicted sea level rise."[87] In addition, Maine, Massachusetts, and Rhode Island have each adopted some form of "rolling easement" to ensure that wetlands or dunes migrate inland as sea level rises and reduce the risk of loss of life and property.[45]

Northeast cities have employed a variety of mechanisms to respond to climate change, including land-use planning, provisions to protect infrastructure, regulations related to the design and construction of buildings, and emergency preparation, response, and recovery.[91] While significant progress has been made, local governments still face limitations of legal authority, geographic jurisdiction, and resource constraints that could be addressed through effective engagement and support from higher levels of government.

Keene, New Hampshire, has been a pilot community for ICLEI's Climate Resilient Communities program for adaptation planning[92] – a process implemented through innovative community engagement methods.[93] The Cape Cod Commission is another example in New England; the Commission has drafted model ordinances to help communities incorporate climate into zoning decision-making. Farther south, New York City has taken numerous steps to implement PlaNYC, a far-reaching sustainability plan for the city, including amending the construction code and the zoning laws and the implementation of measures focused on developing adaptation strategies to protect the City's public and private infrastructure from the effects of climate change;[24] some major investments in protection have even been conceptualized.

Storm Surge Barrier

Figure 16.8. Conceptual design of a storm surge barrier in New York City. (Figure source: Jansen and Dircke 2009).

One widely used adaptation-planning template is the eight-step iterative approach developed by the New York City Panel on Climate Change; it was highlighted in the contribution of the National Academy of Science's Adaptation Panel to America's Climate Choices and adopted by the Committee on America's Climate Choices. It describes a procedure that decision-makers at all levels can use to design a flexible adaptation pathway to address infrastructure and other response issues through inventory and assessment of risk. The key, with respect to infrastructure, is to link adaptation strategies with capital improvement cycles and adjustment of plans to incorporate emerging climate projections[11,94] – but the insights are far more general than that (see the Adaptation Panel Report[95]).

In most cases, adaptation requires information and tools coupled to a decision-support process steered by strong leadership, and there are a growing number of examples in the Northeast. At the smaller, municipal scale, coastal pilot projects in Maryland,[96] Delaware,[97] New York, and Connecticut[90] are underway.

Research and outreach efforts are underway in the region to help farmers find ways to cope with a rapidly changing climate, take advantage of a longer growing season, and reduce greenhouse gas emissions,[56,98] but unequal access to capital and information for strategic adaptation and mitigation remain a challenge. Financial barriers can constrain farmer adaptation.[99] Even relatively straightforward adaptations such as changing varieties are not always a low-cost option. Seed for new stress-tolerant varieties is sometimes expensive or regionally unavailable, and new varieties often require investments in new planting equipment or require adjustment in a wide range of farming practices. Investment in irrigation and drainage systems are relatively expensive options, and a challenge for farmers will be determining when the frequency of yield losses due to summer water deficits or flooding has or will become frequent enough to warrant such capital investments.

Regional activities in the Northeast are also being linked to federal efforts. For example, NASA's Agency-wide Climate Adaptation Science Investigator Workgroup (CASI) brings together NASA facilities managers with NASA climate scientists in local Climate Resilience Workshops. This approach was in evidence at the Goddard Space Flight Center in Maryland, where scientists helped institutional managers address energy and stormwater management vulnerabilities.

Maine's culverts: an adaptation case study

Culverts and the structures they protect are receiving increasing attention, since they are vulnerable to damage during the types of extreme precipitation events that are occurring with increasing frequency in the Northeast (Ch. 2: Our Changing Climate, Key Message 6; Ch. 5: Transportation). For instance, severe storms in the Northeast that were projected in the 1950s to occur only once in 100 years, now are projected to occur once every 60 years.[100]

The Maine Department of Transportation manages more than 97,000 culverts, but individual property owners or small towns manage even more; Scarborough, Maine, for example, has 2,127 culverts. When 71 town managers and officials in coastal Maine were surveyed as part of the statewide Sustainability Solutions Initiative, culverts, with their 50 to 65 year expected lifespan, emerged atop a wish list for help in adapting to climate change.[101]

A research initiative that mapped decisions by town managers in Maine to sources of climate information, engineering design, mandated requirements, and calendars identified the complex, multi-jurisdictional challenges of widespread adaptation for even such seemingly simple actions as using larger culverts to carry water from major storms.[101] To help towns adapt culverts to expected climate change over their lifetimes, the Sustainability Solutions Initiative is creating decision tools to map culvert locations, schedule maintenance, estimate needed culvert size, and analyze replacement needs and costs.

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages:
Results of the Northeast Regional Climate assessment workshop that was held on November 17-18, 2011, at Columbia University, with approximately 60 attendees, were critically important in our assessment. The workshop was the beginning of the process that led to the foundational Technical Input Report (TIR).[2] That 313-page report consisted of seven chapters by 13 lead authors and more than 60 authors in total. Public and private citizens or institutions who service and anticipate a role in maintaining support for vulnerable populations in Northeast cities and communities indicated that they are making plans to judge the demand for adaptation services. These stakeholder interactions were surveyed and engaged in the preparation of this chapter. We are confident that the TIR authors made a vigorous attempt to engage various agencies at the state level and non-governmental organizations (NGOs) that have broader perspectives.

The author team engaged in multiple technical discussions via teleconferences, which included careful review of the foundational TIR[2] and approximately 50 additional technical inputs provided by the public, as well as the other published literature and professional judgment. Discussions were followed by expert deliberation of draft key messages by the authors and targeted consultation with additional experts by the lead author of each key message.

Key message #1 Traceable Account

Heat waves, coastal flooding, and river flooding will pose a growing challenge to the region's environmental, social, and economic systems. This will increase the vulnerability of the region's residents, especially its most disadvantaged populations.

Description of evidence base
The key message and supporting text summarizes extensive evidence documented in the Northeast Technical Input Report.[2] Nearly 50 Technical Input reports, on a wide range of topics, were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications (including many that are not cited) describe increasing hazards associated with sea level rise and storm surge, heat waves, and intense precipitation and river flooding for the Northeast. For sea level rise (SLR), the authors relied on the NCA SLR scenario[12] and research by the authors on the topic (for example, Horton et al. 2010[51]). Recent work[26] summarizes the literature on heat islands and extreme events. For a recent study on climate in the Northeast,[3] the authors worked closely with the region's state climatologists on both the climatology and projections.

The authors also considered many recent peer-reviewed publications[29,32,34,44] that describe how human vulnerabilities to climate hazards in the region can be increased by socioeconomic and other factors. Evaluating coupled multi-system vulnerabilities is an emerging field; as a result, additional sources including white papers[3] have informed this key message as well.

To capture key issues, concerns, and opportunities in the region, various regional assessments were also consulted, such as PlaNYC (http://www.nyc.gov/html/planyc2030) and Boston's Climate Plan (http://www.cityofboston.gov/Images_Documents/A%20Climate%20of%20Progress%20-%20CAP%20Update%202011_tcm3-25020.pdf).

New information and remaining uncertainties
Important new evidence (cited above) confirmed many of the findings from a prior Northeast assessment[10] (see http://nca2009.globalchange.gov/northeast).

The evidence included results from improved models and updated observational data (for example, Liu et al. 2012; Parris et al. 2012; Sallenger et al. 2012[5,9,12]). The current assessment included insights from stakeholders collected in a series of distributed engagement meetings that confirm its relevance and significance for local decision-makers; examples include a Northeast Listening Session in West Virginia, a kickoff meeting in New York City, and New York City Panel on Climate Change meetings.

There is wide diversity of impacts across the region driven by both exposure and sensitivity that are location and socioeconomic context specific. Future vulnerability will be influenced by changes in demography, economics, and policies (development and climate driven) that are difficult to predict and dependent on international and national considerations. Another uncertainty is the potential for adaptation strategies (and to a lesser extent mitigation) to reduce these vulnerabilities.

There are also uncertainties associated with the character of the interconnections among systems, and the positive and negative synergies. For example, a key uncertainty is how systems will respond during extreme events and how people will adjust their short- to long-term planning to take account of a dynamic climate. Such events are, by definition, manifestations of historically rare and therefore relatively undocumented climatology which represent uncertainty in the exposure to climate risk. Nonetheless, these events are correlated, when considered holistically, with climate change driven to some degree by human interference with the climate system. There are uncertainties in exposure.

There are also uncertainties associated with sensitivity to future changes driven to some (potentially significant) degree by non-climate stressors, including background health of the human population and development decisions. Other uncertainties include how much effort will be put into making systems more resilient and the success of these efforts. Another critical uncertainty is associated with the climate system itself.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is:

Very high for sea level rise and coastal flooding as well as heat waves.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

High for intense precipitation events and riverine flooding.

Very high for both added stresses on environmental, social, and economic systems and for increased vulnerability, especially for populations that are already most disadvantaged.

Key message #2 Traceable Account

Infrastructure will be increasingly compromised by climate-related hazards, including sea level rise, coastal flooding, and intense precipitation events.

Description of evidence base

The key message summarizes extensive evidence documented in the Northeast Technical Input Report (TIR).[2] Technical Input reports (48) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

To capture key issues, concerns and opportunities in the region, various regional assessments were also consulted, such as PlaNYC (http://www.nyc.gov/html/planyc2030) and Boston's Climate Plan (http://www.cityofboston.gov/Images_Documents/A%20Climate%20of%20Progress%20-%20CAP%20Update%202011_tcm3-25020.pdf).

In addition, a report by the U.S. Department of Transportation[47] provided extensive documentation that augmented an NGO report.[102] Other sources that support this key message include Horton and Rosenzweig, 2010, Rosenzweig et al. 2011, and Zimmerman and Faris, 2010.[23,51,52]

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings from the prior Northeast assessment: (http://nca2009.globalchange.gov/northeast) which informed the prior NCA.[10]

The new sources above relied on improved models that have been calibrated to new observational data across the region.

It is important to note, of course, that there is wide diversity across the region because both exposure and sensitivity are location- and socioeconomic-context-specific. The wisdom derived from many previous assessments by the National Academy of Sciences, the New York Panel on Climate Change, and the 2009 National Climate Assessment[10,11,95] indicates that future vulnerability at any specific location will be influenced by changes in demography, economics, and policy. These changes are difficult to predict at local scales even as they also depend on international and national considerations. The potential for adaptation strategies (and to a lesser extent mitigation) to reduce these vulnerabilities is yet another source of uncertainty that expands as the future moves into the middle of this century.

Assessment of confidence based on evidence

We have **very high** confidence in projected sea level rise and increased coastal flooding, and **high** confidence for increased intense precipitation events. This assessment of confidence is based on our review of the literature and submitted input and has been defended internally and externally in conversation with local decision-makers and representatives of interested NGOs, as well as the extensive interactions with stakeholders across the region reported in the Northeast TIR.[2]

Very high confidence that infrastructure will be increasingly compromised, based on the clear evidence of impacts on current infrastructure from hazards such as Hurricane Irene, and from the huge deficit of needed renewal identified by a diverse engineering community.[46]

Key message #3 Traceable Account

Agriculture, fisheries, and ecosystems will be increasingly compromised over the next century by climate change impacts. Farmers can explore new crop options, but these adaptations are not cost- or risk-free. Moreover, adaptive capacity, which varies throughout the region, could be overwhelmed by a changing climate.

Description of evidence base

The key message summarizes extensive evidence documented in the Northeast Technical Input Report.[2] Technical Input reports (48) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. The Traceable Account for Key Message 1 provides the evidence base on sea level rise, flooding, and precipitation.

Various regional assessments were also consulted to capture key issues, concerns and opportunities in the region with particular focus on managed (agriculture and fisheries) and unmanaged (ecosystems) systems (for example, Buonaiuto et al. 2011; Wolfe et al. 2011[56,70,78]).

Species and ecosystem vulnerability have been well documented historically in numerous peer-reviewed papers in addition to the ones cited in the TIR.[2] There have also been many examples of impacts on agriculture of climate variability and change in the Northeast (for example, Wolfe et al. 2008[57]). Most note that there is potential for significant benefits associated with climate changes to partially offset expected negative outcomes for these managed systems (for example, Hatfield et al. 2011[54])

New information and remaining uncertainties

Important new evidence (cited above, plus Najjar et. al. 2010,[83] for example) confirmed many of the findings from the prior Northeast assessment (http://nca2009.globalchange.gov/northeast) which informed the 2009 NCA.[10] These new sources also relied on improved models that have been calibrated to new observational data across the region.

Agriculture, fisheries, and ecosystems in the Northeast are strongly linked to climate change and to other changes occurring outside the region and beyond the boundaries of the United States. These changes can influence the price of crops and agricultural inputs such as fertilizer, for example, as well as the abundance of ecosystem and agricultural pests and the abundance and range of fish stocks. Other uncertainties include imprecise understandings of how complex ecosystems will respond to climate- and non-climate-induced changes and the extent to which organisms may be able to adapt to a changing climate.

Assessment of confidence based on evidence

Based on our assessment, we have **very high** confidence for climate impacts (especially sea level rise and storm surge) on ecosystems; and we have **high** confidence for climate impacts on agriculture (reduced to some degree, compared to our level of confidence about ecosystems, by uncertainty about the efficacy and implementation of adaptation options). Confidence in fisheries changes is **high** since confidence in both ocean warming and fish sensitivity to temperature is **high**.

Key message #4 Traceable Account

While a majority of states and a rapidly growing number of municipalities have begun to incorporate the risk of climate change into their planning activities, implementation of adaptation measures is still at early stages.

Description of evidence base

The key message relies heavily on extensive evidence documented in the Northeast Technical Input Report (TIR).[2] Technical Input reports (48) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Many of the key references cited in the TIR reflected experiences and processes developed in iterative stakeholder engagement concerning risk management[94,103] that have been heavily cited and employed in new venues – local communities like Keane (NH) and New York City, for example.

Various regional assessments were also consulted to capture key issues, concerns and opportunities in the region (for example, for Delaware, Maine, Maryland, and Long Island, NY). In addition, there have been agency and government white paper reports describing proposed adaptation strategies based on climate impact assessments.[11,90] We discovered that 10 of the 12 states in the Northeast have statewide adaptation plans in place or under development (many plans can be found at: http://georgetownclimate.org/node/3324).

New information and remaining uncertainties

That most Northeast states have begun to plan for adaptation is a matter of record. That few adaptation plans have been implemented is confirmed in Technical Inputs submitted to the National Climate Assessment process as well as prior assessments (http://nca2009.globalchange.gov/northeast), which informed the 2009 NCA.[10]

Key uncertainties looking forward include: 1) the extent to which proposed adaptation strategies will be implemented given a range of factors including competing demands and limited funding; 2) the role of the private sector and individual action in adaptation, roles which can be difficult to document; 3) the extent of the federal role in adaptation planning and implementation; and 4) how changes in technology and the world economy may change the feasibility of specific adaptation strategies.[11]

Assessment of confidence based on evidence

This Key Message is simply a statement of observed fact, so confidence language is not applicable.