Confronting Climate Change in the U.S. Northeast

SCIENCE, IMPACTS, AND SOLUTIONS

Prepared by the Northeast Climate Impacts Assessment Synthesis Team:

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About the Northeast Climate Impacts Assessment

The Northeast Climate Impacts Assessment (NECIA) is a collaborative effort between the Union of Concerned Scientists (UCS) and a team of independent experts to develop and communicate a new assessment of climate change and associated impacts on key climate-sensitive sectors in the northeastern United States. The goal of the assessment is to combine state-of-the-art analyses with effective outreach to provide opinion leaders, policy makers, and the public with the best available science upon which to base informed choices about climate-change mitigation and adaptation.

NECIA oversight and guidance is provided by a multidisciplinary Synthesis Team of senior scientists:

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The material presented in this report is based primarily on the peer-reviewed research of the NECIA collaborators listed below. Most of this research is also presented in more technical detail in the formal scientific literature, including a special issue of the journal *Mitigation and Adaptation Strategies to Global Change* (in press, 2008).

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This work builds on the NECIA climate research reported in *Climate Change in the U.S. Northeast* available at *www.northeastclimateimpacts.org*, as well as the foundation laid by considerable previous research. This includes the New England, Metropolitan East Coast, and Mid-Atlantic regional assessments carried out under the auspices of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change *(http://www.usgcrp.gov/usgcrp/nacc/)* as well as the recent assessment of climate change impacts on North America by the Intergovernmental Panel on Climate Change (Field et al. 2007).[1]

1 Field, C.B., L.D. Mortsch, M. Brlacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, M.J. Scott, J. Andrey, D. Cayan, M. Demuth, A. Hamlet, G. Jones, E. Mills, S. Mills, C.K. Minns, D. Sailor, M. Saunders, D. Scott, and W. Solecki. 2007. North America, Chapter 14. In *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK: Cambridge University Press. In press.

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Executive Summary

From the sandy beaches of New Jersey to the rocky shores of Maine, and inland from the cornfields of Pennsylvania to the forested mountains of New York, Vermont, and New Hampshire, the northeastern United States boasts enormous geographical and climatic diversity within a relatively small area. The character and economy of the Northeast have been profoundly shaped over the centuries by its varied and changeable climate—the pronounced seasonal cycle that produces snowy winters, verdant springs, humid summers, and brilliant autumns, and the year-to-year and seasonal variability that includes extreme events such as nor'easters, ice storms, and heat waves.

This long-familiar climate has already begun changing in noticeable ways, however. Since 1970 the Northeast has been warming at a rate of nearly 0.5 degrees Fahrenheit (°F) per decade. Winter temperatures have risen even faster, at a rate of 1.3°F per decade from 1970 to 2000. This warming has been correlated with many other climate-related changes across the region, including:

- More frequent days with temperatures above 90°F
- A longer growing season
- Less winter precipitation falling as snow and more as rain
- Reduced snowpack and increased snow density
- Earlier breakup of winter ice on lakes and rivers
- Earlier spring snowmelt resulting in earlier peak river flows
- Rising sea-surface temperatures and sea levels

All of these observed changes are consistent with those expected to be caused by global warming. The world's leading climate scientists concluded in February 2007 that it is "unequivocal" that Earth's climate is warming, and that it is "very likely" (a greater than 90 percent certainty) that the heat-trapping emissions from the burning of fossil fuels and other human activities have caused "most of the observed increase in globally averaged temperatures since the mid-twentieth century."[1] Thus, the Northeast and the rest of the world face continued warming and more extensive climate-related changes to come—changes that could dramatically alter the region's economy, landscape, character, and quality of life.

In October 2006, the Northeast Climate Impacts Assessment (NECIA) released a report titled *Climate Change in the U.S. Northeast*.[2] This report was the product of a collaborative research effort that drew on recent advances in climate modeling to assess how global warming may further affect the Northeast's climate. Using projections from three state-of-the-art global climate models, the report compared the types and magnitude of climate changes that will result from two different scenarios of future heat-trapping emissions. The first (the higher-emissions scenario) is a future where people—individuals, communities, businesses, states, and nations—allow emissions to continue growing rapidly, and the second (the lower-emissions scenario) is one in which societies choose to rely less on fossil fuels and adopt more resource-efficient technologies.

These scenarios represent strikingly different emissions choices that societies may make. However, they do not represent the full range of possible emissions futures. A number of factors, including unrestrained fossil-fuel use, could drive global emissions above the "high-emissions" scenario, while rapid, concerted efforts to adopt clean, efficient technologies could reduce emissions below the "lower-emissions" scenario used in this study.

How will emissions choices affect the likely climate future for the Northeast?

NECIA climate projections found that over the next several decades, temperatures across the Northeast will rise 2.5°F to 4°F in winter and 1.5°F to 3.5°F in summer regardless of the emissions choices we make now (due to heat-trapping emissions released in the recent past). By mid-century and beyond, however, today's emissions choices generate starkly different climate futures.

> Unrestrained fossil-fuel use could drive global emissions above the "higher-emissions" scenario, while rapid, concerted efforts to adopt clean, efficient technologies could reduce emissions below the "lower-emissions" scenario.

By late this century, under the higher-emissions scenario:

- Winters in the Northeast could warm by 8°F to 12°F and summers by 6°F to 14°F above historic levels.
- The length of the winter snow season could be cut in half across northern New York, Vermont, New Hampshire, and Maine, and reduced to a week or two in southern parts of the region.
- Cities across the Northeast, which today experience few days above 100°F each summer, could average 20 such days per summer, and more southern cities such as Hartford and Philadelphia could average nearly 30 days.
- Short-term (one- to three-month) droughts could occur as frequently as once each summer in the area of the Catskills and the Adirondacks, and across the New England states.
- Hot summer conditions could arrive three weeks earlier and last three weeks longer into the fall.
- Global average sea level is conservatively projected to rise one to two feet.

In contrast, substantially smaller climate-related changes can be expected if the Northeast and the world reduce emissions consistent with the lower-emissions scenario used in this study—typically, about half the change expected under the higher-emissions scenario. For example, Northeast winters are projected to warm 5°F to 8°F above historic levels by late-century, and summers by 3°F to 7°F.

This report builds upon and extends these findings. NECIA collaborators—leading scientists and economists from universities and research institutions across the Northeast and the nation—have used the NECIA climate projections to assess the impacts of these two very different future Northeast climates on vital aspects of the region's life and economy: coastal areas, marine fisheries, forests, agriculture, winter recreation, and human health. They also describe actions that can be taken today in the Northeast to reduce emissions and help avoid the most severe impacts of global warming and to adapt to the unavoidable changes that past emissions have already set in motion.

What might the climate changes projected under the higher- or lower-emissions scenarios mean for the economy and quality of life in the Northeast?

By late this century, if the higher-emissions scenario prevails:

- The extreme coastal flooding that now occurs only once a century could strike New York City on average once every decade.
- Increasing water temperatures may make the storied fishing grounds of Georges Bank unfavorable for cod.
- Pittsburgh and Concord, NH, could each swelter through roughly 25 days over 100°F every summer—compared with roughly one day per summer historically—and even typically cool cities such as Buffalo could average 14 days over 100°F each year, amplifying the risk of heat-related illnesses and death among vulnerable populations.
- In Philadelphia, which already ranks tenth in the nation for ozone pollution, the number of days failing to meet federal air-quality standards is projected to quadruple (if local vehicle and industrial emissions of ozone-forming pollutants are not reduced).
- Only western Maine is projected to retain a reliable ski season.
- The hemlock stands that shade and cool many of the Northeast's streams could be lost—much like the American elm—to a pest that thrives in warmer weather, further threatening native brook trout in the Adirondacks and elsewhere.
- Climate conditions suitable for maple/beech/birch forests are projected to shift dramatically

northward, while conditions suitable for spruce/fir forests—a primary source of sawlogs and pulpwood as well as a favored recreation destination—would all but disappear from the region.

- As their forest habitat changes, many migratory songbirds such as the Baltimore oriole, American goldfinch, and song sparrow are expected to become less abundant.
- Parts of Massachusetts, New Jersey, Pennsylvania, and other areas in the Northeast are likely to become unsuitable for growing certain popular varieties of apples, blueberries, and cranberries.
- Unless farmers can afford cooling technologies, milk production across much of the region is projected to decline 5 to 20 in certain months.

If, instead, the region and the world begin now to make the transition to the lower-emissions pathway:

- New York City is projected to face today's 100-year flood every two decades on average.
- Georges Bank would remain suitable for adult cod, although yield and productivity may decline as these waters become less hospitable for the spawning and survival of young cod.
- Philadelphia's severe ozone-pollution days will increase by 50 percent (assuming that local vehicle and industrial emissions of ozone-forming pollutants are not reduced).
- In addition to western Maine, the North Country of New York and parts of Vermont and New Hampshire may retain reliable ski seasons.
- Climate conditions suitable for maple/beech/birch forests would shift only in the southern part of the region.
- Winter temperatures may prevent a deadly hemlock pest from infesting the northern part of the region.
- Less extensive (although still substantial) changes in the region's bird life are expected.
- Much of the region is projected to remain suitable for traditional apple and berry crops.
- Reductions in milk production (up to 10 percent) would remain confined primarily to New Jersey and small areas of Pennsylvania.

In many cases, however, the impacts of global warming are projected to be similar under either of the two emissions scenarios presented here.

- Atlantic City, NJ, and Boston are expected to experience today's once-a-century coastal flooding once every year or two on average by the end of the century.
- The lobster fisheries in Long Island Sound and the coastal waters off Rhode Island and south of Cape Cod are likely to decline significantly by mid-century, and cod are expected to disappear from these southern waters by century's end.
- The number of days over 90°F is expected to triple in many of the region's cities, including Boston, Buffalo, and Concord, NH.
- Hotter, longer, drier summers punctuated by heavy rainstorms may create favorable conditions for more frequent outbreaks of mosquito-borne disease such as West Nile virus.
- Most of the region is likely to have a marginal or non-existent snowmobile season by mid-century.
- Warmer winters will shorten the average ski and snowboard seasons, increase snowmaking requirements, and drive up operating costs.
- Spruce/fir forests such as the Great North Woods are expected to lose significant area, diminishing their value for timber, recreation, and wildlife habitat. Certain species that depend on these forests, such as the Bicknell's thrush, are projected to disappear from the region.
- Weed problems and pest-related damage are expected to escalate, increasing pressures on farmers to use more herbicides and pesticides.

Clearly, under either of the emissions scenarios explored by NECIA, the Northeast can anticipate substantial—and often unwelcome or dangerous—changes during the rest of this century. Heat-trapping emissions released in the recent past have already committed the world to further warming over the next few decades. Decision makers at all levels of society should recognize the need to adapt to these unavoidable changes. The intensity of the warming and the severity of the related impacts the Northeast will face beyond mid-century, however, depend on action to curb further emissions starting now.

As noted above, the emissions scenarios used in this assessment represent neither a ceiling nor a floor on future levels of carbon dioxide (CO_2) and other heat-trapping gases in the atmosphere. The lower-emissions scenario describes a world in which atmospheric concentrations of CO_2 rise from ~380 parts per million (ppm) today to ~550 ppm by the end of the century, in contrast to 940 ppm under the higher-emissions scenario. However, many lines of evidence indicate that even greater emissions reductions, and thus less severe impacts, are well within our reach. The latest assessment of the Intergovernmental Panel on Climate Change (IPCC)

As both a global leader in technology, finance, and innovation and a major source of heat-trapping emissions, the Northeast is well positioned to help drive national and international progress in reducing emissions.

describes the technical and economic potential for stabilizing atmospheric concentrations of heat-trapping gases at or below the equivalent of 450 ppm of CO_2.[3,4] Achieving such a target would require the United States and other industrialized nations to make deep emissions reductions by mid-century—on the order of 80 percent below 2000 levels—along with substantial reductions by developing countries.

How can decision makers, businesses, and individuals in the Northeast meet the challenge of a changing climate?

In the Northeast, as well as elsewhere in the United States and the world, there is growing momentum to pursue deep emissions reductions consistent with staying below the lower-emissions pathway described in this report. In 2001, for example, New England governors and Eastern Canadian premiers signed an agreement committing their states and provinces to a comprehensive Climate Change Action Plan that includes a long-term goal of reducing regional emissions 75 to 85 percent below then-current levels. More recently, policy makers in California and New Jersey have set ambitious near- and longer-term targets for reducing emissions, and similar measures are being debated in statehouses across the country and in Congress.

Of course, actions in the Northeast alone will not be sufficient to reduce global warming. But as both a global leader in technology, finance, and innovation and a major source of heat-trapping emissions, the Northeast is well positioned to help drive national and international progress in reducing emissions. Concerted, sustained efforts to reduce emissions by just over 3 percent per year on average would achieve nearly half of the total reductions needed by 2030, putting the region well on track for achieving the 80 percent mid-century goal.

From individual households to industry and government, decision makers across the Northeast have myriad options available today to move toward this goal across the region's four major CO_2-emitting sectors (electric power, buildings, transportation, and industry), and many are already taking innovative steps to do just that. These options include:

- Accelerating the region's transition from fossil fuels to clean, renewable energy resources (e.g., solar, wind, geothermal), through wise energy choices aided by market incentives and regulations.
- Embracing efficiency by purchasing energy-efficient lighting and small appliances and replacing vehicles, heating and cooling systems, motors, and large appliances with more efficient models as the existing equipment reaches the end of its useful life.
- Using state and municipal zoning laws, building codes, and incentives to encourage energy-efficient buildings, discourage urban sprawl, provide low-emissions transportation alternatives, and avoid development in vulnerable coastal areas and floodplains.

Concerted actions such as these to meet the climate challenge can also advance other widely shared goals in the Northeast such as enhancing regional energy and economic security, creating jobs, producing cleaner air, and building a more sustainable economy.

What is needed now is a strong, sustained, and well-coordinated effort between governments at all levels, businesses, civic institutions, and individuals to adopt policies, programs, and practices that accelerate the adoption of clean, efficient energy choices. The costs of delay are high. For every year of delay in beginning significant emissions reductions, global concentrations of heat-trapping gases rise higher and the goal of avoiding dangerous climate change becomes more difficult and more costly to achieve. Given the century-long lifetime of CO_2 in the atmosphere, the longer we wait to take action, the larger and more concentrated in time our emissions reductions will need to be to limit the extent and severity of climate change.

Although the task of reducing emissions may seem daunting, the nation achieved a similarly rapid energy transformation only a century ago as it shifted from gaslights and buggies to electricity and cars over a few short decades. In 1905 only 3 percent of U.S. homes had electricity, virtually none had cars, and few could envision how these innovations would transform America and its economy half a century later. Similarly, slightly less than 3 percent of our electricity is currently generated by non-hydroelectric renewable energy technologies. Yet with foresight and perseverance, we can dramatically modify our energy system once again, moving from fossil fuels to renewables to avoid severe climate change.

Because past emissions have committed the region and the world to a certain unavoidable level of global warming over the next several decades, decision makers in the Northeast must also begin to develop timely and forward-looking strategies that can help vulnerable constituencies adapt to the consequences. Aggressive steps to reduce emissions can limit the regional impacts of climate change and thus improve the prospect that ecosystems and societies will find effective ways to adapt. In turn, timely and effective adaptation measures will help reduce the vulnerability of people and ecosystems to the warming that cannot be avoided.

Decision makers can help the region adapt through policies and management actions that reduce our exposure to climate risks (such as catastrophic flooding) and also increase the ability of vulnerable sectors and communities to cope with ongoing changes and recover from extreme events or disasters. For each adaptation measure considered, policy makers and managers must carefully assess the potential barriers, costs, and unintended social and environmental consequences.

The very character of the Northeast is at stake. NECIA findings make clear that the emissions choices we make here in the Northeast and globally will have dramatic implications for the climate our children and grandchildren will inherit. The Northeast states and their municipal governments have a rich array of proven strategies and policies available to meet the climate challenge in partnership with businesses, institutions, and an increasingly supportive public.

The time to act is now.

CHAPTER ONE

Our Changing Northeast Climate

KEY FINDINGS

- **The burning of fossil fuels and other human activities are increasing the levels of carbon dioxide and other heat-trapping gases in the atmosphere, causing global average temperatures to rise.**
- **The Northeast is already experiencing changes consistent with global warming: rising temperatures, decreasing snow cover, and earlier arrival of spring.**
- **Due to emissions in the recent past, average temperatures across the Northeast are projected to rise another 2.5 to 4 degrees Fahrenheit (°F) in winter and 1.5°F to 3.5°F in summer above historic levels over the next several decades. The extent and severity of climate change beyond mid-century, however, will be determined by emissions choices we make now—in the Northeast and around the world.**
- **If emissions remain high, average temperatures across the Northeast are projected to rise, by late this century, 8°F to 12°F above historic levels in winter and 6°F to 14°F in summer. Cities across the Northeast are projected to average 20 days per summer over 100°F and some (such as Philadelphia and Hartford, CT) could average nearly 30 such days. The length of the winter snow season could be cut in half across Maine, New Hampshire, northern New York, and Vermont.**
- **Smaller climate-related changes can be expected if the world follows the lower-emissions pathway used in this assessment—typically about half the change expected under the higher-emissions scenario. By late-century, for example, average temperature is projected to increase 5°F to 8°F in winter and 3°F to 7°F in summer under the lower-emissions scenario. Most cities are projected to average only a few days over 100°F. In the northern part of the region, a decrease in the length of the winter snow season of more than 25 percent is projected.**
- **Because some additional warming is inevitable, it is now essential to prepare to adapt to the changes that cannot be avoided.**

BACKGROUND

The character and economy of the Northeast are defined in no small part by its dramatically changeable climate: the pronounced seasonal cycle that produces snowy winters, verdant springs, pleasant summers, and colorful autumns; the year-to-year and day-to-day variability that includes extreme events such as nor'easters, ice storms, and heat waves; and the moderating influence of offshore currents such as the Gulf Stream. Throughout the Northeast—defined here as the states of Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont—this long-familiar climate has been changing in noticeable ways.

Temperatures have been rising, particularly in winter, and the number of extremely hot summer days has been increasing. Snow cover is decreasing, and spring is arriving earlier in the year. All of these changes are consistent with those expected from human-caused climate change.[1]

The world's leading climate scientists, through the Intergovernmental Panel on Climate Change (IPCC), confirmed in February 2007 that it is "unequivocal" that Earth's climate is warming and "very likely" (a greater than 90 percent certainty) that heat-trapping gases from human activities have caused most of the warming experienced over the past 50 years. This latest IPCC assessment corroborates and strengthens the previous conclusions of 11 national science academies, including that of the United States, that the primary drivers of climate change are the burning of fossil fuels (such as coal and oil) and tropical deforestation—activities that release carbon dioxide (CO_2) and other heat-trapping or "greenhouse" gases into the atmosphere. CO_2 concentrations have already risen to their highest levels in more than 650,000 years and, due largely to these rising CO_2 levels, average annual temperatures in the Northern Hemisphere have increased more than 1.3°F over the past century.[2]

If emissions of heat-trapping gases continue to grow unabated, the Northeast can expect dramatic temperature increases over the course of this century.

Since 1970, the Northeast has been heating up at a rate of 0.5°F per decade. Winter temperatures have been rising even faster—1.3°F per decade between 1970 and 2000. Observers have noted a correlation between this warming and many other changes across the region, including:[3]

- More frequent days with temperatures above 90°F
- A longer growing season
- Earlier first-leaf and first-bloom dates for plants
- Less precipitation falling as snow and more as rain
- Reduced snowpack and increased snow density
- Earlier breakup of winter ice on lakes and rivers
- Earlier spring snowmelt, resulting in earlier peak spring stream flow
- Earlier migration of Atlantic salmon and mating of frogs
- Rising sea-surface temperatures

In January 2007—the world's hottest January on record[4]—residents of the Northeast received an unmistakable preview of winters to come, delighting some but causing economic hardship for others. In mid-January, for example, sled dogs pulled tourists in golf carts through the snowless woods of western Maine; ski slopes were covered in mud and slush; ice-fishing derbies were cancelled; Adirondack visitors went hiking instead of snowshoeing; apple growers feared their trees would burst into bloom much too early; daffodils bloomed in New York City;[5] and people played golf, frolicked on the beach, and strolled the vineyards of Long Island in warm sunshine.[6,7] Not until late January did a series of snowstorms blanket the Northeast and bring back more typical winter conditions.

As the Northeast continues to warm, even more extensive climate-related changes are projected—changes that have the potential to dramatically alter many aspects of the region's economy, ecosystems, character, and quality of life. Some changes are now unavoidable. For example, the degree of warming that can be expected over the next few decades (including additional warming of up to 4°F in winter and 3.5°F in summer) is unlikely to be significantly curbed by any reductions in emissions of heat-trapping gases undertaken in the Northeast and the rest of the world during that time period.

These near-term climate changes have already been set in motion by emissions over the past few decades. Two factors account for this delayed response: the long lifetime of the heat-trapping gases we have already released, which can remain in the atmosphere for tens or hundreds of years, and the time it takes for the oceans to respond to increasing atmospheric levels of heat-trapping gases.[8] Policy makers and communities across the Northeast must, therefore, begin adapting to the unavoidable consequences of this warming. (See the Meeting the Climate Challenge chapter.)

Toward mid-century and beyond, however, the extent of further warming will be determined by actions taken—starting now and continuing over the next several decades—to reduce emissions. While actions to reduce emissions in the Northeast alone will not stabilize the climate, the region is a center of global leadership in technology, finance, and innovation. Home to 57 million people, or one of every five Americans, it is also the seventh largest source of carbon dioxide emissions from energy use when compared with entire nations. (See the Meeting the Climate Challenge chapter.) As such, the Northeast is well positioned to be a technology and policy leader in reducing emissions and driving the national and international progress essential to avoid the most severe impacts of global warming.

In the Northeast, as well as elsewhere in the United States and internationally, momentum is building to pursue deep reductions in emissions. Northeast states are taking action—both individually and in cooperation, building on each other's commitments and modeling multi-state climate policy for the nation.[9] Within states, a range of decision makers—

cities, universities, corporations, and households—are coming to terms with the significance of their emissions choices and implementing their own emissions-reduction strategies. (See the Meeting the Climate Challenge chapter.)

Global warming, of course, is only one of a number of pressures related to human activities that are changing the character and economy of the Northeast and the well-being of its people. Other factors include population growth in the urban corridor from Philadelphia to Boston (already the most densely populated area in the nation); urban sprawl and vacation-home development that are consuming farmland and open space and altering the nature of the coastline and countryside;[10] aging infrastructure and persistent poverty in some of the region's oldest cities; serious air and water pollution; ongoing coastal erosion; and changing economics in traditional industries such as fishing, farming, timber harvesting, and manufacturing. Such pressures will combine with—and potentially exacerbate—the effects of climate change to help define the future of the Northeast.

This chapter summarizes how climate in the Northeast is projected to change this century under two different scenarios of continued human emissions of heat-trapping gases. Developed by the IPCC, these scenarios represent the highest and lowest projections of future emissions used to assess future climate change. (See the text box on assessing future climate change.)

These scenarios represent strikingly different emissions choices that societies may make. It is important to note, however, that they do not represent the full range of possible emissions futures. A number of factors could drive global emissions even higher than assumed in the higher-emissions (A1fi) scenario, while concerted efforts to reduce emissions could move them well below the lower-emissions (B1) scenario used in this study. (See the Meeting the Climate Challenge chapter.)

PROJECTED CLIMATE CHANGE

Seasonal and annual temperatures

Since 1900, the annual average temperature across the Northeast has risen 1.5ºF, with most of this warming occurring in just the past few decades. Since 1970, regional temperatures have been warming at an average rate of almost 0.5ºF per decade. Winter temperatures are rising even faster, for a total warming of more than 4ºF between 1970 and 2000.

Hot Summers in the City

As the number of days over 90°F climbs, particularly under the higher-emissions scenario, city dwellers such as these (shown in the streets of New York City) may experience increasing discomfort and potentially severe threats to their health.

During this century, temperatures across the Northeast are projected to continue rising, due to both past and future emissions of heat-trapping gases.

- Over the next several decades, temperatures are projected to continue increasing more in winter (from 2.5°F to 4°F) than in summer (1.5°F to 3.5°F) under both the higher- and lower-emissions scenarios.
- By mid-century, differences between the two scenarios begin to appear: winter temperatures are projected to be 4°F to 7°F warmer than the historic average and summers 4°F to 8°F warmer under the higher-emissions scenario. By contrast, an increase of 4°F to 5°F is projected for winter and 2°F to 5°F for summer under the lower-emissions scenario.
- By the end of the century, temperatures in winter are projected to be 8°F to 12°F warmer and in summer 6°F to 14°F warmer under the higher-emissions scenario. Under the lower-emissions scenario, winters are projected to warm between 5°F and 8°F, and summers between 3°F and 7°F.

Heat index and "migrating" states

How cold or hot it feels depends not only on temperature but also on wind and humidity. As Northeast-

CONTINUED ON PAGE 6

Assessing Future Climate Change in the Northeast

In order to project changes in temperature and other climate variables over the coming decades, scientists must address two key uncertainties. The first is directly related to human activity: how much CO_2 and other heat-trapping gases will our industrial and land-use activities emit over the coming century? The second is scientific in nature: how will the climate respond to these emissions (e.g., how much will temperatures rise in response to a given increase in atmospheric CO_2)?

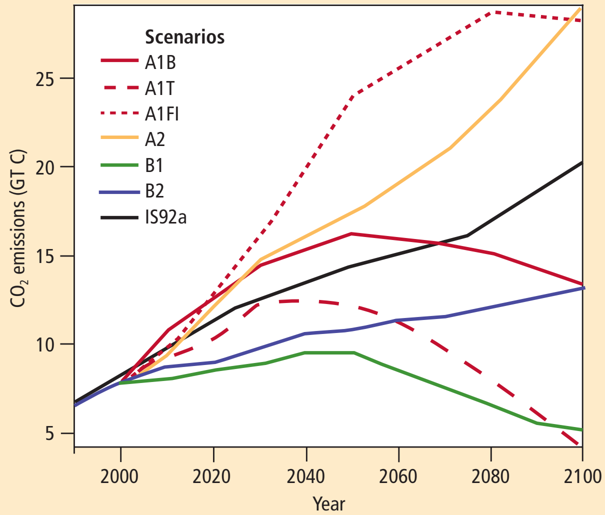
To address the first uncertainty, the IPCC has developed a set of possible futures, or scenarios, that project global levels of emissions of heat-trapping gases based on a wide range of development variables including population growth, energy use, and other societal choices.[11]

NECIA analyses used the IPCC's A1fi and B1 scenarios to represent possible higher- and lower-emissions choices, respectively, over the course of the century. The higher-emissions scenario represents a world with fossil fuel-intensive economic growth and a global population that peaks mid-century, then declines. New and more resource-efficient technologies are not introduced until late in the century. Atmospheric CO_2 concentrations reach 940 parts per million (ppm) by 2100—more than triple pre-industrial levels.

The lower-emissions scenario also represents a world with high economic growth and a global population that peaks mid-century. However, this scenario assumes a much faster shift to less fossil fuel-intensive industries and more resource-efficient technologies. This causes CO_2 emissions to peak around mid-century then decline to less than our present-day emissions rates by the end of the century. Atmospheric CO_2 concentrations reach 550 ppm by 2100—about double pre-industrial levels.

How this report's climate projections were developed

To estimate the range of potential changes in the Northeast's climate and address the second uncertainty—how the climate will respond to increasing emissions—NECIA researchers used the IPCC's higher- and lower-emissions scenarios as input to



IPCC Emissions Scenarios

Projected carbon emissions for the IPCC SRES scenarios.[12] The higher-emissions scenario (A1fi) corresponds to the dotted red line while the lower-emissions scenario (B1) corresponds to the green line.

three state-of-the-art global climate models, each representing different climate "sensitivities" (see below). These models are among the best of the latest generation of climate models; they use mathematical equations to represent physical laws and solve these equations using a three-dimensional grid laid over the globe.

Climate simulations require that each of the climate system's major components (atmosphere, ocean, land surface, cryosphere, and biosphere) be represented by sub-models, along with internal and interactive processes. These sub-models are thoroughly tested and compared with observations of the current climate and other periods in our climatic past.[13,14]

Climate sensitivity is defined as the temperature change resulting from a doubling of atmospheric carbon dioxide concentrations relative to pre-industrial times, and determines the extent to which temperatures will rise under a given increase in atmospheric concentrations of heat-trapping gases. Because some of the processes at work in the earth-atmosphere system are not yet fully understood, they are represented somewhat differently in various global climate models. This results in different climate sensitivities of different models. The greater the climate sensitivity, the greater the extent of projected climate change for a given increase in CO_2. That is why NECIA analyses used three different climate models to generate the projections described in this study: the U.S. National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1 model, the United Kingdom Meteorological Office's Hadley Centre Climate Model version 3 (HadCM3), and the National Center for Atmospheric Research's Parallel Climate Model (PCM). The first two have medium and medium-high climate sensitivities, respectively, while the third has low climate sensitivity.

Confidence in using these global models to assess the Northeast's future climate is based on results from a detailed analysis that indicates these models are able to reproduce not only key features of the regional climate (e.g., seasonal shifts in atmospheric circulation and the North Atlantic Oscillation) but also climate changes that have already been observed across the region over the past century (e.g., rising temperatures, increases in precipitation and storms producing heavy precipitation).

Global climate models produce output in the form of geographic grid-based projections of daily, monthly, and annual temperatures, precipitation, winds, cloud cover, humidity, and a host of other climate variables. The grid cells range in size from 50 to 250 miles on a side. To transform these global projections into "higher-resolution" regional projections (which look at changes occurring across tens of miles rather than hundreds) NECIA scientists used well-established statistical and dynamical downscaling techniques.[15,16]

Uncertainties in climate modeling and the workings of the earth-atmosphere system remain. Several lines of evidence suggest that the climate-model projections used in the NECIA assessment may be relatively conservative. (See the text box on The Possibility of More Rapid or Abrupt Climate Change.)

How this report's climate projections are presented

The collaborative research presented in this chapter is drawn from the October 2006 report *Climate Change in the U.S. Northeast: A Report of the Northeast Climate Impacts Assessment* and the peer-reviewed scientific articles on which that report was based.[17,18,19,20] In this chapter (and throughout this report), except where otherwise noted:

- All projections are based on the average of the three global climate models described above: GFDL, HadCM3, and PCM.
- "Historical" is used to refer to the baseline period of 1961–1990; "over the next several decades" is used to describe model results averaged over the period 2010–2039; "mid-century" and "late-century" refer to model results averaged over the periods 2040–2069 and 2070–2099, respectively.

erners know all too well, a sunny winter day with no wind might feel warmer than a damp, windy spring day, while humid summer days can be stifling. For that reason, heat index—defined as the temperature *perceived* by the human body based on both air temperature and humidity—can be a better measure of how hot it may "feel" in the future than the actual temperature. Under the higher-emissions scenario, an average summer day in the region is projected to feel 12°F to 16ºF warmer than it did historically. The impact of changes in heat index due to global warming can be illustrated by comparing future summers in the Northeast with current summers to the south. For example:

- In terms of average heat index, mid-century summers in Massachusetts are projected to resemble those of New Jersey today under the lower-emissions scenario, and those of Maryland under the higher-emissions scenario.
- Late-century summers in the Tri-State region around New York City could resemble those of South Carolina today under the higher-emissions scenario, and those of Virginia under the lower-emissions scenario.
- Late-century summers in New Hampshire and upstate New York are projected to resemble current summers in North Carolina and Georgia, respectively, under the higher-emissions scenario, and those of Virginia under the lower-emissions scenario.

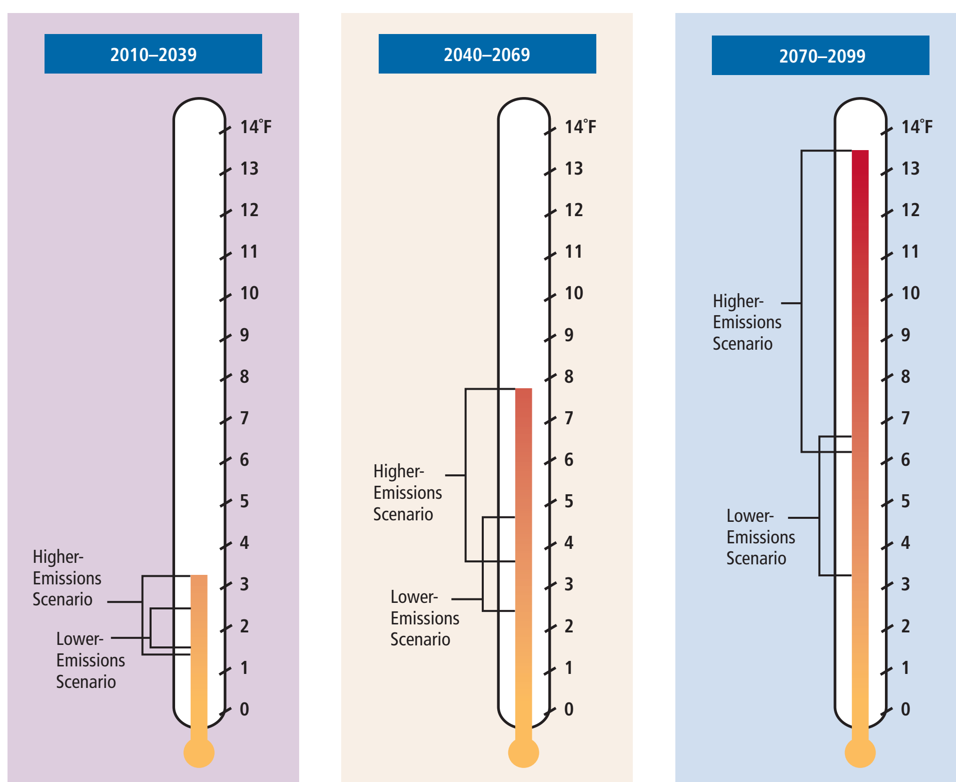
Heat waves and temperature extremes

Heat waves with multiple consecutive days over 90ºF descend on parts of the Northeast each summer, sometimes more than once per year. The average number of days per year with temperatures exceeding 90ºF has roughly doubled over the past 45 years; cities across the Northeast currently experience an average of five such days in the northern part of the region and up to 20 such days in the more southern and inland areas. The number of days over 100ºF ranges from none for more northern cities such as Buffalo up to two for more southern cities such as New York and Philadelphia.

Climate change is projected to dramatically increase the number of these extremely hot days.

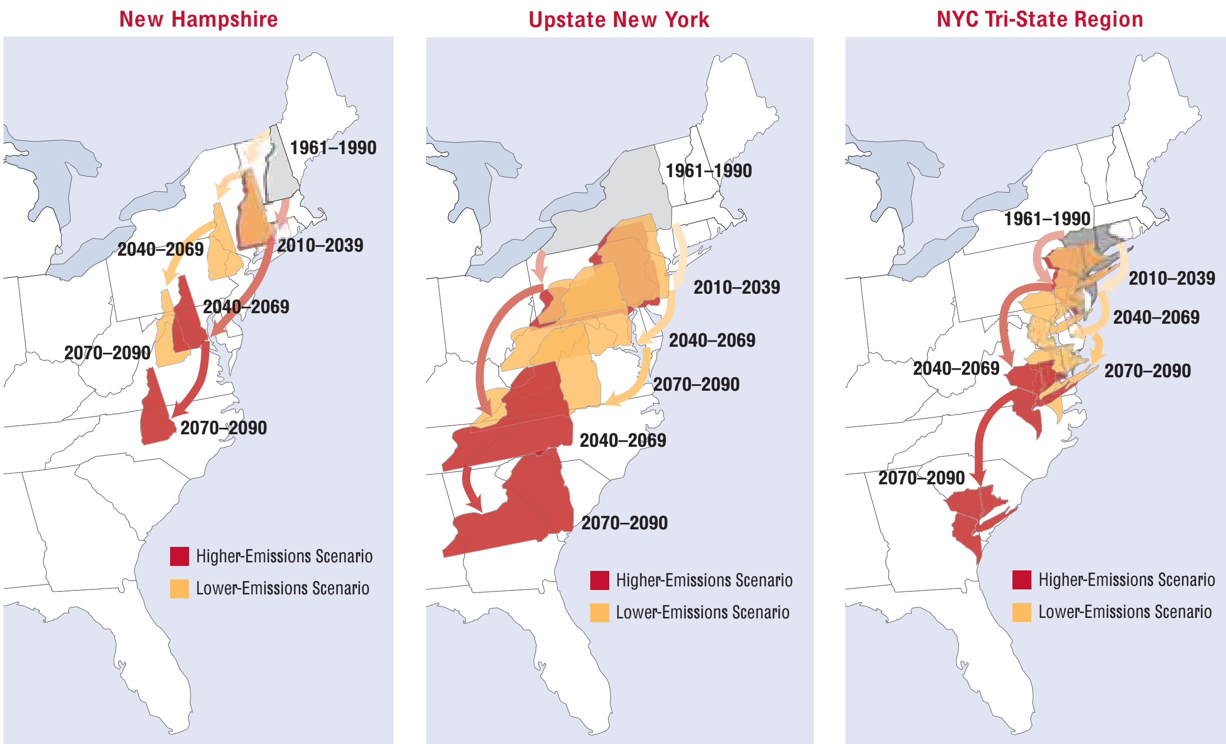
- By late-century, many northeastern cities can expect 60 or more days per year over 90ºF under

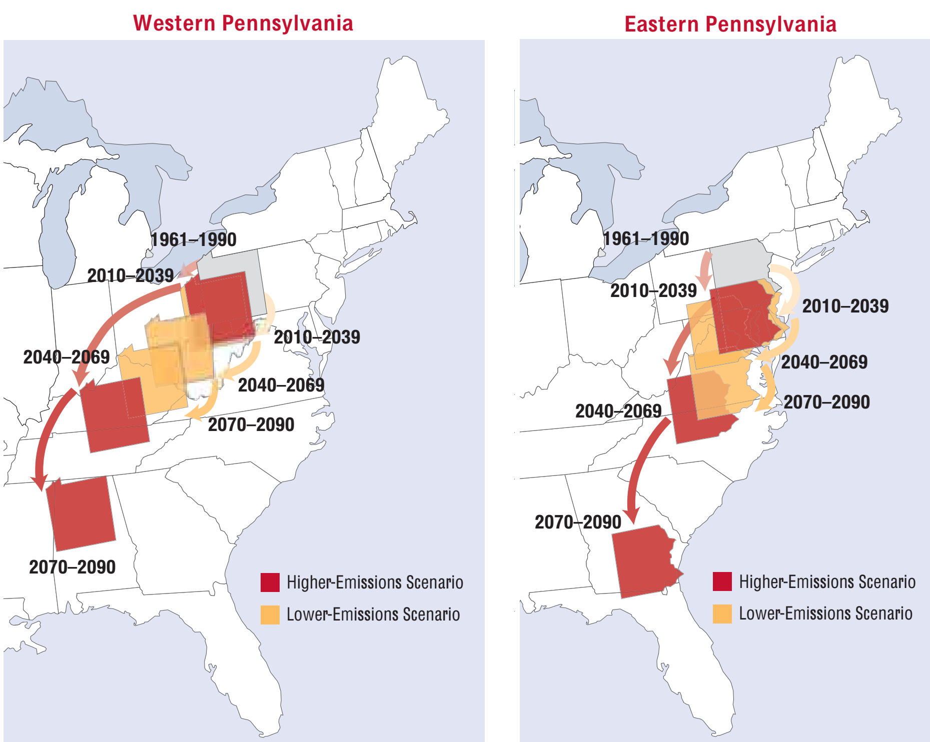
FIGURE 1: Changes in Regional Average Summer Temperature



The Northeast is already experiencing rising temperatures, with potentially dramatic warming expected later this century, especially if emissions of heat-trapping gases continue along the path of the higher-emissions scenario. These "thermometers" show projected increases in regional average summer temperatures for three time periods: early-, mid-, and late-century.

FIGURE 2: Migrating State Climates





Changes in average summer heat index—a measure of how hot it actually feels, given temperature and humidity—could strongly affect quality of life in the future for residents of the Northeast. Red arrows track what summers could feel like in, for example, the NYC Tri-State region (the greater New York City metropolitan region, encompassing parts of New Jersey and Connecticut) over the course of the century under the higher-emissions scenario. Yellow arrows track what summers in these states would feel like under a lower-emissions scenario.

the higher-emissions scenario and 30 or more such days under the lower-emissions scenario.
- The number of days per summer over 100ºF could increase by late-century to between 14 and 28 days under the higher-emissions scenario and between three and nine days under the lower-emissions scenario.

The implications of this projected increase in extremely hot days across the Northeast for heat-related health and agriculture are described in the health and agriculture chapters of this assessment, respectively.

Precipitation

Precipitation in the Northeast can vary greatly from year to year and month to month. Though the region experienced a severe drought in the early 1960s, overall, annual average precipitation has been gradually increasing (5 to 10 percent) across the region since 1900.

Most of this annual increase has been evenly split between spring, summer, and fall, with little increase in winter precipitation. In the past few decades, though, this pattern has been reversed, with winter precipitation increasing slightly. (As winter temperatures have risen, more winter precipitation has been falling as rain and less as snow; see the section on snow.) Over the course of the century, winter precipitation is projected to continue increasing, with little change in other seasons.

- The Northeast is projected to see a steady increase in annual precipitation under either emissions scenario, with a total increase of around 10 percent (about four inches per year) by the end of the century.
- By the end of the century, winter precipitation could increase an average of 20 to 30 percent, with the greatest increases under the higher-emissions scenario. A much greater proportion of winter precipitation would be expected to fall as rain rather than as snow.
- Overall, little change in summer rainfall is expected, although projections are highly variable.

Extreme precipitation

During the 1980s and 1990s, the Northeast experienced a rise in heavy-precipitation events, defined as more than two inches of rain falling in 48 hours. To assess possible changes in such events, we used this measure and two others: precipitation intensity (the average amount of rain that falls on any rainy day) and the intensity of once-a-year extreme-precipitation events (the total precipitation that falls during the five consecutive days with the most precipitation in a given year).

Under both emissions scenarios, rainfall is expected to become more intense and periods of heavy rainfall are expected to become more frequent. By all three measures:[21]

- Increases in precipitation intensity of 8 to 9 percent are projected by mid-century, and 10 to 15 percent by the end of the century. In other words, wet days will become wetter.
- The number of heavy-precipitation events is projected to increase 8 percent by mid-century, and 12 to 13 percent by the end of the century. So in addition to having more rain when it does rain, there will also be more two-day periods with heavy downpours.
- Increases are also projected for the wettest five-day period of each year. By mid-century, 10 percent more rain is projected to fall during these events; by the end of the century, 20 percent more rain is projected.

Extreme precipitation also occurs during major coastal storms, such as nor'easters. (See the text box on changing storm patterns.) Increases in extreme precipitation can affect water quality and outbreaks of waterborne disease, replenishment of groundwater supplies, soil erosion, and flood risks both in urban areas and agricultural fields in the Northeast. (See the agriculture chapter and the text box on water resources.)

Evaporation, soil moisture, runoff, and drought

The Northeast's lush green hills, clear forest streams, and mountain lakes suggest a landscape rich in water resources. (See the text box on water resources.) This is largely true, although the Northeast is subject to its share of droughts (defined here as occurring when monthly soil moisture falls more than 10 percent below the long-term mean) and human demand for water continues to rise.

In the future, however, climate-related changes in the timing and amount of water availability, as well as projected increases in the frequency of drought, may fundamentally alter the landscape.

- Rising winter temperatures will melt snow faster and earlier, likely increasing runoff and soil moisture in winter and early spring. These increases could be followed by reductions in soil moisture

Damage and Disruption from Extreme Precipitation

In Rochester, NH, heavy rains in May 2006 flooded the Axe Handle Brook, leading to this bridge collapse. Extensive flooding in south and central New Hampshire at that time resulted in millions of dollars in damage and disaster aid to residents. Global warming is expected to increase the occurrence and severity of extreme precipitation in the Northeast, especially under the higher-emissions scenario.

in late summer and early fall as warmer temperatures drive evaporation rates higher.

- Projected winter and spring increases in soil moisture, as well as summer and fall decreases, will generally be greater under the higher-emissions scenario.

For the purposes of this analysis, droughts are classified as short-term (lasting one to three months), medium-term (three to six months), or long-term (more than six months). Historically, short-term droughts occur once every two years across most of the Northeast and once every three years over northern Maine, upstate New York, and western Pennsylvania. Medium-term droughts are far less common; historically, they have occurred once every 15 years in the inland regions listed above, but not at all in some coastal areas. Long-term droughts have occurred on average less than once every 30 years. By the end of the century short- and medium-term droughts in the Northeast are projected to increase dramatically under the higher-emissions scenario, with only slight increases under the lower-emissions scenario. Under the higher-emissions scenario short-term droughts may be as frequent as once per year in the area of the Catskills, the Adirondacks, and across the New England states.[22]

More frequent droughts and decreases in summer and fall soil moisture can affect agricultural production in the region. (See the agriculture chapter and the text box on water resources.)

Stream flow and water supply

Rising winter and spring temperatures in the Northeast have already resulted in visible changes to ice cover and stream flow. Since 1850, for example, the date of spring ice-out (i.e., the complete thawing of surface ice) on lakes has shifted nine days earlier in the northern part of the region and 16 days earlier in the southern part. (See the text box on lake ice.) Similarly, the highest spring stream flow in the northern part of the region now arrives 7 to 14 days earlier than in the past.

These changes are directly related to air temperature, which determines the timing of snowmelt and ice breakup. As temperatures continue to rise, snow and ice will melt even earlier.

- Under both emissions scenarios the date of peak spring stream flow is projected to occur an additional four to five days earlier over the next several decades, and seven to nine days earlier by mid-century.
- By the end of the century, peak stream flow could occur 10 days earlier under the lower-emissions scenario and more than two weeks earlier under the higher-emissions scenario.

Under the higher-emissions scenario short-term droughts may be as frequent as once per year in the area of the Catskills, the Adirondacks, and across the New England states.

- As winter precipitation increases and warmer temperatures melt snow faster, high-flow events are projected to occur more frequently, especially under the higher-emissions scenario and in the northern part of the region. In Maine, New Hampshire, and Vermont the probability of high-flow events may increase as much as 80 percent, accompanied by an increased risk of flooding.

Another critical period for stream flow and water supply arrives in late summer when heat, evaporation, and water demand all peak, creating extended low-flow periods. The timing and number of these episodes have remained largely unchanged over the past century in the Northeast.

- Little change is expected under the lower-emissions scenario.
- Under the higher-emissions scenario, however, stream flow during the lowest week of the year is projected to drop 10 percent or more by the end of the century. Low-flow periods are also projected to arrive more than a week earlier in the summer and extend several weeks longer into the fall.

Overall, stream flow is projected to become more extreme—higher in winter, likely increasing flood risk, and lower in summer, exacerbating drought. (See the text box on water resources as well as the agriculture chapter and the text box on cold-water fish.)

Winter snow

Snow is an iconic characteristic of winter in the Northeast and is part and parcel of many revered winter activities and traditions. But rising temperatures over the past few decades have already produced some noticeable changes in the region's snow. For example, the "slushiness" of snow—its wetness or density—has increased while the number of snow-covered days has decreased.[23]

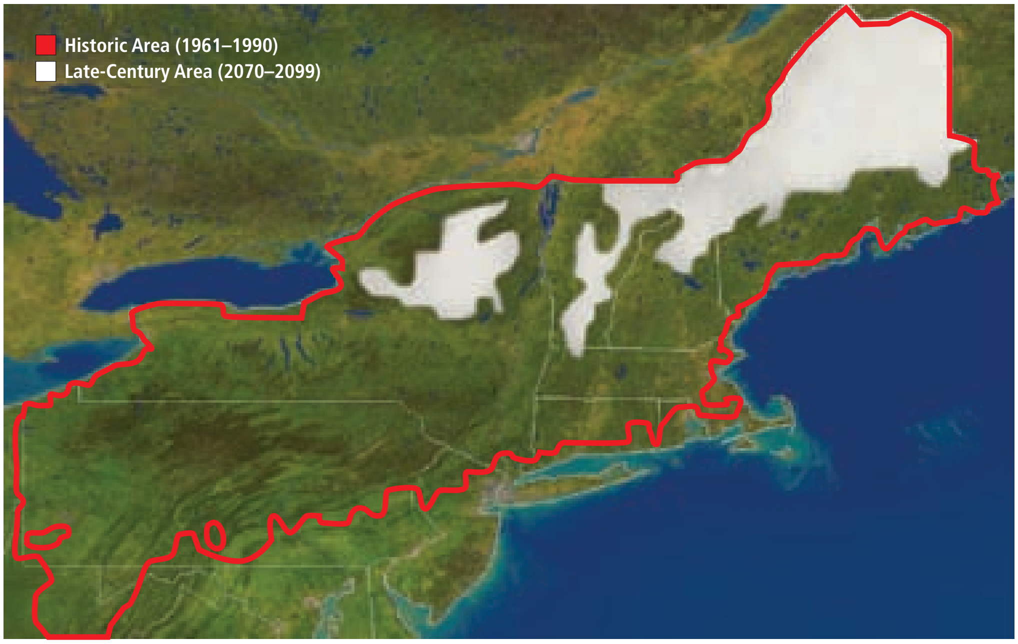
The number of snow-covered days per winter month in the Northeast ranges, on average, from close to zero in southern Pennsylvania to 30 in parts of Maine, New Hampshire, northern New York, and Vermont. As temperatures rise, snow is projected to appear later in the winter and disappear earlier in the spring, shortening the overall snow season. By late-century:[24]

- Most of the Northeast is projected to lose 10 to 15 snow-covered days per winter month under the higher-emissions scenario and four to eight such days under the lower-emissions scenario. The largest decreases may occur across the central part of the region, where the threshold between snow and no snow is most sensitive.
- The northern part of the region, currently snow-covered for almost the entire winter season, is projected to lose up to half of its snow-covered days under the higher-emissions scenario, or more than one-quarter under the lower-emissions scenario.

Low-Flow Conditions Threaten Wildlife in Northeast Rivers

Scientists monitor low water levels in Maine's Sheepscot River during an extended drought. Survival rates for fish such as salmon and trout diminish when water levels in rivers and streams are dangerously low. By late-century, such low-flow conditions could arrive a week earlier and last several weeks longer each year under the higher-emissions scenario, with little change to seasonal patterns expected under the lower-emissions scenario.

FIGURE 3: The Changing Face of Winter



If higher emissions prevail, a typical snow season may become increasingly rare in much of the Northeast toward the end of the century. The red line in the map captures the area of the northeastern United States that, historically, has had at least a dusting of snow on the ground for at least 30 days in the average year. The white area shows the projected retreat of this snow cover by late-century to higher altitudes and latitudes, suggesting a significant change in the character of a Northeast winter.

- The southern and western parts of the Northeast could experience as few as 5 to 10 snow-covered days in winter, compared with 10 to 45 days historically.

The impacts of a declining snowpack and increase in winter rain on industries such as skiing and snowmobiling are addressed in the winter recreation chapter of this assessment; impacts on seasonal stream flow and water supplies are addressed in the text box on water resources.

Timing of seasons

The blooming of certain flowers and the budding of leaves on trees are welcome harbingers of spring and important indicators of climate change. The first-bloom dates for lilacs, for example, have shifted four days earlier since the 1960s, and even greater shifts of six to eight days have been observed for grape vines and apple trees. In general, most documented dates related to plant and animal appearances in the Northeast are occurring earlier in the year.

- First-leaf and first-bloom dates are projected to arrive more than two days earlier per decade under the higher-emissions scenario—arriving almost three weeks earlier by the end of the century. Under the lower-emissions scenario these dates would arrive roughly one day earlier per decade (or one to two weeks earlier by the end of the century).
- By mid-century summer is projected to arrive in the Northeast an average of six days earlier under the lower-emissions scenario and 11 days earlier under the higher-emissions scenario. Summer is also projected to extend longer into the fall—10 days longer under the lower-emissions scenario and 16 days longer under the higher-emissions scenario.
- By late-century even greater changes are projected, with summers beginning nine days earlier under the lower-emissions scenario and 21 days earlier under the higher-emissions scenario. Similarly, summer is projected to extend 12 days longer into the fall under the lower-emissions scenario and more than three weeks longer under the higher-emissions scenario.

Another important seasonal indicator of climate change is the length of the growing (or frost-free) season. The Northeast's growing season—measured from the date of the last spring frost to the date of the first fall frost—typically lasts 185 days, or about half the year. From 1915 to 2003 the length of the growing season has been increasing an average of 0.7 day per decade; from 1970 to 2000 the trend accelerated to an increase of roughly 2.5 days per decade. While first-freeze dates are occurring somewhat later in the fall, growing season length is increasing primarily due to last-freeze dates occurring earlier in the spring.

- By mid-century the Northeast's growing season is projected to be two to four weeks longer.

Harbingers of Spring Arrive Earlier and Earlier

A longtime harbinger of spring, lilacs now bloom four days earlier on average than four decades ago. Global warming will bring spring earlier and push fall frosts later into the year.

- By late-century the growing season may be an average of four weeks longer under the lower-emissions scenario and six weeks longer under the higher-emissions scenario.

Changes in the growing season may create opportunities for farmers who have the resources to try growing crops more suited to a warmer climate, but cause problems for farmers of apple, grape, and berry varieties that require long winter-chill periods. (See the agriculture chapter and the text box on gardening.)

Ocean temperatures and sea-level rise

Regional sea-surface temperatures have increased 1ºF since 1900 and are projected to continue increasing, though at a slightly slower rate than regional air temperatures. By the end of the century, regional sea-surface temperatures are projected to rise an additional 6°F to 8˚F under the higher-emissions scenario and 4°F to 5˚F under the lower-emissions scenario. These warmer temperatures may adversely affect native marine species in the Northeast, including the commercially important fisheries whose southernmost range is limited by warm temperatures. (See the marine chapter.)

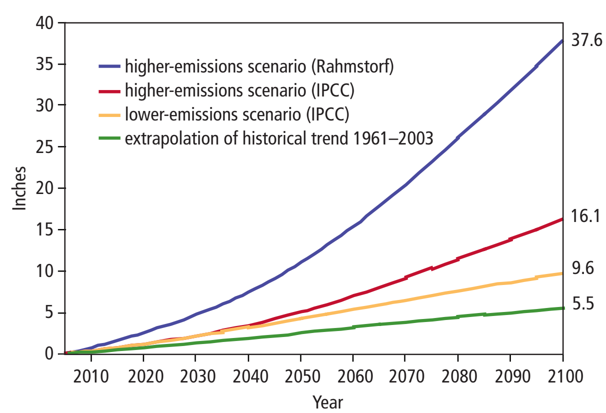
Globally, sea levels have been rising since the end of the last ice age and are rising even faster now. This acceleration is caused by two different mechanisms related to increasing temperatures: thermal expansion of seawater as it warms and increasing inflow of water from melting ice sheets and glaciers.

Assuming no further warming, a continuation of the recent historical rate of global sea-level rise could lead to a nearly six-inch increase over 2005 levels by the end of the century.[25] (See the coastal chapter.) Factoring in further global warming, however, the IPCC projects that global sea levels will rise between 7 and 14 inches under the lower-emissions scenario and between 10 and 23 inches under the higher-emissions scenario.[26] (See Figure 4, which shows the averages or mid-ranges for each of the sea-level rise scenarios considered here.)

A more recent analysis, however, has projected much greater end-of-century sea-level rise: on the order of 2 to 4.5 feet above 2005 levels under the higher-emissions scenario.[27] Even these projections may be conservative in that they do not account for the rapid rate of ice breakup and melting currently being observed in the polar ice sheets (particularly those of Greenland), nor do they assess the potential for further acceleration of this melting.

The Northeast's highly developed coastline, the health of its barrier beaches, estuaries, and other

FIGURE 4: Projected Rise in Global Sea Level Relative to 2005



This graph depicts the average or mid-range of a number of different sea-level rise (SLR) simulations: a continuation of recent observed SLR rates (green line), the mid-range of the most recent IPCC projections under the lower-emissions scenario (yellow line), the mid-range of the recent IPCC projections under the higher-emissions scenario (red line), and the mid-range of a more recent set of projections under the higher-emissions scenario (blue line).[28]

important coastal ecosystems, and the integrity of coastal freshwater aquifers are highly vulnerable to projected sea-level rise. (See the coastal chapter and the text box on Northeast water resources.)

CONCLUSION

The Northeast's climate is already changing, and it is clear from these projections that a much greater degree of change can be expected over the coming century (particularly under the higher-emissions scenario). Changes in air and sea-surface temperature, sea levels, periods of extreme heat, extreme precipitation and drought, and other features of the Northeast's climate will have a considerable impact on the region's character, its major ecosystems, and climate-sensitive sectors of its economy. The following chapters examine how emissions choices will affect the impacts of global warming on many of the Northeast's most vulnerable sectors and communities.

Because some additional warming is inevitable, it is now essential to prepare to adapt to the changes that cannot be avoided. But, starting today, deep reductions in emissions in the Northeast and across the world can reduce the extent and severity of global warming well below those described by the lower-emissions scenario used in this study. The Meeting the Climate Challenge chapter highlights the strategies and opportunities available to aggressively reduce emissions across the Northeast and to adapt to those changes that are now unavoidable.

The Possibility of More Rapid or Abrupt Climate Change

The climate projections presented in this report are based on relatively conservative global climate model simulations. These models are not able to incorporate all of the processes that can interact with human-driven changes to affect Earth's climate; some of these processes operate on very long timescales while others operate on very small spatial scales.

For instance, global climate models can accurately reproduce the warming observed around the world and across the Northeast during the past century, not only in terms of the long-term trends but also the accelerated warming observed in the Northeast since 1970 (an average of nearly 0.5°F per decade). However, these large-scale global models consistently underestimate the rapid winter warming the Northeast has experienced over the past 30 years (1.3°F per decade).

Part of the explanation may be that the models are not designed to reproduce the timing of observed natural climate variability. Neither are they designed to incorporate the small-scale but important feedback effects of local changes such as the decrease in surface snowpack over highly variable terrain that has been observed over the past 30 years. Diminished snowpack can exacerbate winter warming because exposed ground absorbs more solar radiation than snow-covered ground and the warmer ground can, in turn, drive additional snowmelt.

Projections of sea-level rise used in this report may also be quite conservative because they do not account for the rapid rate of decay and melting of the major polar ice sheets currently being observed (especially in Greenland), nor do they incorporate the potential for further acceleration of this melting.[29,30,31,32,33] There is growing concern that the warming projected for this century could cross a threshold beyond which the major ice sheets of Greenland and West Antarctica could be irreversibly destabilized. The meltwater from the Greenland ice sheet alone could raise the global average sea level by about 20 feet over several centuries.

Finally, the amount of warming expected over this and coming centuries may lead to a slowing of the ocean's thermohaline circulation. This system of deep-water currents acts like a giant conveyor belt, distributing heat around the globe by transporting warm equatorial waters north and moving cold polar waters south. In the past, sudden changes in the thermohaline circulation are believed to have triggered abrupt climate changes in the Northern Hemisphere. State-of-the-art climate models project a weakening rather than a total collapse of the thermohaline circulation in the coming centuries. Current understanding of the dynamics governing the conveyor belt and the potential impact of its weakening on the Northeast is limited.[34]

CHAPTER TWO

Coastal Impacts

KEY FINDINGS

- **By the end of this century, global sea level is projected to rise 7 to 14 inches under the lower-emissions scenario and 10 to 23 inches under the higher-emissions scenario used in this study. Several lines of evidence indicate that these projections may be quite conservative.**
- **Even under these projections, many areas of the densely populated Northeast coast face substantial increases in the extent and frequency of coastal flooding and are at increased risk of severe storm-related damage.**
  - **Boston and Atlantic City, for example, can expect a coastal flood equivalent to today's 100-year flood every two to four years on average by mid-century and almost annually by the end of the century.**
  - **New York City is projected to face flooding equivalent to today's 100-year flood once every decade on average under the higher-emissions scenario and once every two decades under the lower-emissions scenario by century's end.**
- **Sea-level rise is also projected to permanently inundate low-lying coastal areas and increase shoreline erosion and wetland loss. The areas most vulnerable to shoreline erosion include portions of Cape Cod, Long Island, and most of coastal New Jersey.**
- **Because of the erosive impact of waves (especially storm waves), the extent of shoreline retreat and wetland loss is projected to be many times greater than the loss of land caused by the rise in sea level itself.**
- **The high concentration of population, property, infrastructure, and economic activity in coastal areas of the Northeast create considerable challenges for emergency response, hazard mitigation, and land-use planning. Combined with the conservative nature of these sea-level rise projections, these factors leave little room for delay or complacency in reducing heat-trapping emissions and adapting to rising sea levels.**

BACKGROUND

The Northeast coastline stretches from the broad sandy beaches of New Jersey to the rocky cliffs of northern Maine, encompassing extensive headlands and barrier islands, tidal marshes and estuaries, bays and sounds—each with a rich history that has shaped the character and economy of the region for centuries. More than half of the U.S. population—some 155 million people—now lives along the nation's coasts. One-third of them (nearly 53 million people) live in the densely populated coastal counties of the Northeast, and their numbers are growing rapidly, especially around urban centers such as Boston and New York City.[1]

An even larger number of people visit the coast each year: for example, the population of certain towns in coastal New Jersey—the "Jersey Shore"—triples in summer. The Northeast has experienced an unprecedented boom in housing and resort development as well as an escalation in coastal

Atlantic City's Vulnerability to Global Warming

Built on a barrier island, Atlantic City—as well as most of the Jersey Shore—is highly vulnerable to sea-level rise, increased coastal flooding from storm surges, and erosion. With global warming, today's 100-year coastal floods are projected to recur in Atlantic City every four years by mid-century and every year or two by the end of this century under either emissions scenario.

property values for much of the past century. In 2004, the value of insured coastal property from New Jersey to Maine exceeded $3.7 trillion.[2]

Today, among coastal states exposed to hurricane strikes, only Florida ranks higher than each of the Northeast states in terms of the percentage of total property considered coastal—and thus vulnerable to catastrophic damage from a coastal storm.[3] Despite this tremendous risk to people and property, the coast's appeal, especially as a place to escape oppressive summer heat, may not diminish in coming decades.

Along with population growth and development have come the filling in of marshes, dredging of channels and harbors, ocean disposal of sewage and industrial wastes, runoff of nutrients such as nitrogen and phosphorus, replacement of beach sand, and increased construction of jetties, seawalls, and other structures intended to stabilize the naturally dynamic coastline. As coastal infrastructure increases, so does the potential for loss of life and property from coastal erosion, storms, and flooding.

Global warming affects coastal areas by altering air temperatures and rainfall over coastal lands, raising coastal water temperatures, and increasing the average sea level. In a warmer climate, global sea levels increase because water expands as it warms, and melting glaciers and ice sheets on continents add water to the oceans. Global sea levels have been rising at a variable rate since the end of the last ice age (18,000 years ago) due to the melting of continental ice sheets.

Sea level also rises at different rates at different locations, depending on local land movement up or down. The resulting "relative sea-level rise" is the local net increase in sea level due to changes in both global average sea level and local land movement. Along much of the Northeast shoreline—from New Jersey to Cape Cod— there is evidence that relative sea level is rising faster than the global average because the land is gradually subsiding.[4,5] An acceleration in global sea-level rise due to global warming, on top of ongoing local changes, would put these shores at heightened risk of inundation and damage.

Mere continuation of the recent trend (1961–2003) in global sea-level rise could result in nearly six inches of sea-level rise over 2005 levels by the end of this century.[6] This projection represents the most conservative estimate. Factoring in further warming, however, global sea level is projected to rise between 7 and 14 inches by the end of the century under the lower-emissions scenario and between 10 and 23 inches under the higher-emissions scenario.[7] The difference between these two projections is relatively small because of the long time lag

A Nor'easter Drives Water Ashore

Waves destroy homes in Saco, ME, during an April 2007 nor'easter that created storm surges, coastal flooding, and substantial damage from New Jersey to Maine. With rising sea levels, the frequency of major flooding from storms such as this is projected to increase dramatically by the end of the century.

between atmospheric temperature increases and global sea-level rise.

More recent analysis projects even greater end-of-century sea-level rise—on the order of 2 to 4.5 feet above 2005 levels with higher emissions (see the climate chapter, Figure 4).[8] This scenario is included here to suggest the possible impacts of sea-level rise above the upper end of the range of current IPCC projections. However, all of the projections presented in this study are conservative because they do not account for the rapid rate of decay and melting of the major polar ice sheets currently being observed (especially in Greenland), nor do they incorporate the potential for further acceleration of this melting.[9]

COASTAL FLOODING

The Northeast's coast is vulnerable to a variety of storms, ranging from rare but intense tropical storms and hurricanes to less intense but more frequent "nor'easters." (See the text box on changes in storm patterns.) As a storm approaches shallow nearshore waters it frequently generates a storm surge, a wind- and pressure-driven swell that can temporarily increase sea level and flood low-lying coastal areas. When these storm surges occur in conjunction with high tide (or over several tidal cycles), flood-related property damage can be catastrophic and the risk to human life substantial.[10]

That is exactly what happened on September 21, 1938, when the most intense (category 3 or greater) hurricane to strike the Northeast during the past century made landfall in central Long Island, then moved north into Connecticut, Massachusetts, and Vermont. The storm surge combined with a high tide raised the water level a reported 10 feet above normal tide levels along the open coast and sent 13-foot storm surges into parts of Narragansett Bay and Buzzards Bay. Storm surges washed over nearly every barrier beach in the region and cut many inlets through them. In the absence of warning systems, more than 600 people died and property damage at the time was estimated at $400 million.[11]

As a storm approaches shallow nearshore waters it frequently generates a storm surge, a wind- and pressure-driven swell that can temporarily increase sea level and flood low-lying coastal areas.

Since 1850, 19 hurricanes have made landfall in the Northeast, six of them in a relatively active period between 1935 and 1960.[12] By one estimate, hurricane damages along the East Coast over the past 80 years have averaged $5 billion per year, with most of the damage occurring during the largest storms.[13]

Continued warming of the oceans appears to be increasing the intensity of Atlantic hurricanes[14,15,16] and, despite sophisticated forecasting capabilities and warning systems, risks to human life could also increase because of the difficulties of evacuating densely populated areas in the face of fast-moving storms. Relative sea level has already risen about six inches in southern New England since 1938,[17,18] and further sea-level rise will only intensify threats to life and property from all storms, both hurricanes and nor'easters. If the 1938 Long Island/New England hurricane were to hit today it would likely cause about $20 billion in insured property damage.[19]

Compared with hurricanes, nor'easters are typically lower-energy storms, but they occur more frequently and generally last longer and cover larger areas, allowing some of these storms to have a greater impact on coastal areas. For example, a nor'easter on December 11–12, 1992, produced near-record winds and flooding for this type of storm, disrupting New York City's transportation system, prompting evacuation of many coastal communities in New Jersey and Long Island, and destroying numerous homes.[20] Past storms have shown that certain areas within the New York City metropolitan area are highly vulnerable to storm surges and flooding,[21] prompting improvements to the local emergency-management systems.[22] As sea level rises further, however, damage greater than what occurred in this and other past storms could be produced even by a less severe storm.

As sea level rises, damage greater than what occurred in past storms could be produced by a less severe storm.

To anticipate the potential frequency and extent of damage from future coastal floods, researchers use a benchmark called the "100-year flood" that allows them to ask how frequently a flood of similar magnitude may occur in the future as sea levels—and thus the baseline for flooding—rise. (See the text box on 100-year floods.) It also allows researchers to ask what the future flood level of a storm surge with the same probability of occurrence (1 percent per year) may be. It is important to note that the 100-year flood represents a historical average, and severe flooding associated with storm surges has occurred in the Northeast in intervals much shorter than 100 years.[23]

A NECIA analysis identified the average return time between major coastal flooding events (e.g., the 100-year flood) and combined the results with different scenarios of future sea-level rise to generate projections of future coastal floods.[24] Five coastal sites in the Northeast were examined: Atlantic City, NJ; Boston; New London, CT; New York City; and Woods Hole, MA. Researchers projected both the change in recurrence intervals of today's 100-year coastal flood in those locations, as well as the floodwater heights associated with future 100-year floods, based on projections of sea-level rise by mid- and late-century.[25] The results outlined below focus only on the IPCC's most recent and relatively conservative projections for both the lower- and higher-emissions scenarios. Because of the time lag between atmospheric warming and global sea-level rise outlined above, these results, while dramatic, show relatively subtle differences between the two emissions scenarios in the first half of the century.

By mid-century substantial changes in coastal flooding are already evident.

The 100-Year Flood

Historical records of extreme events allow us to calculate the approximate intervals at which floods of a certain height have occurred in the past and to estimate the frequency at which they may recur in the future. A frequently used benchmark is the "100-year flood"—the maximum flood elevation likely to be equaled or exceeded on average once every century in a given location. In any one year, there is a 1 percent probability that a 100-year flood will occur. Similarly, a 10-year flood has a 10 percent probability of occurring in any given year, and a 1,000-year flood has a 0.1 percent probability. It is important to note that these are not predictions, but rather statements of probabilities based on historical averages.

The expected elevation of a 100-year flood at a given location is commonly used in emergency planning and on flood-risk maps to show areas vulnerable to storm-related flooding of that magnitude. The 100-year flood elevation is also a standard used to determine the need for flood insurance or "flood-proofing" requirements attached to building permits, and the applicability of other environmental regulations and protective measures. In this sense, the 100-year flood is one way of capturing society's threshold for risk—areas exposed to this level of risk require greater precautionary measures to prevent extensive damage than those with a lower exposure.

- Substantial increases in the maximum elevation of major coastal floods are projected for all five locations, but particularly Boston and Atlantic City.[26]
- Substantial increases in the frequency of today's 100-year floods are expected at all five locations:[27]
  - Every two to three years in Boston on average (under the higher- and lower-emissions scenarios, respectively)
  - Every four years in Atlantic City on average under either scenario
  - Every 46 to 50 years in New York City and Woods Hole (under the higher- and lower-emissions scenarios, respectively)
  - Every 56 to 61 years in New London (under the higher- and lower-emissions scenarios, respectively)

By 2100, the significance of emissions choices for sea-level rise and coastal flooding become more apparent as both the maximum heights and recurrence intervals of coastal floods increase, particularly under the higher-emissions scenario.

- Most locations are projected to experience increases over the current 100-year-flood elevation of roughly 1.5 feet under the higher-emissions scenario and roughly one foot under the lower-emissions scenario.
- Today's 100-year coastal floods are projected to recur much more often. On average:
  - Under the higher-emissions scenario,
    - Every year or two in Boston and Atlantic City
    - Every nine years in Woods Hole
    - Every 11 years in New York City
    - Every 17 years in New London
  - Under the lower-emissions scenario,
    - Every year or two in Boston and Atlantic City
    - Every 21 years in Woods Hole
    - Every 22 years in New York City
    - Every 32 years in New London

These projections are based on changes in sea-level rise alone and do not include other potential changes such as shifts in shoreline position or changes in storm frequency, intensity, or track. If storms strike the Northeast's coast with greater frequency and intensity, for instance, the frequency of coastal floods (and associated damages) would be expected to rise even more.

The relatively modest differences in projected flooding under the two emissions scenarios obscure the long-term risk associated with global sea-level rise. Scientists have expressed considerable concern that as emissions increase and the climate continues to warm, there is a growing risk that the climate will cross a critical threshold beyond which the collapse of the polar ice sheets, especially Greenland's, will be inevitable and practically irreversible (particularly under the higher-emissions scenario). This would lead to far greater sea-level rise in this century than what is projected here, even if the complete collapse would take several hundred years. (See the climate chapter and the text box on the possibility of more abrupt climate change.)

As sea-level rise accelerates and today's 100-year floods become tomorrow's two-year or 10-year floods, new 100-year flood levels will need to be calculated for use in coastal zone management and other regulatory purposes. In Boston, for example, as today's 100-year maximum flood height of 9.7 feet becomes a more common occurrence, the new 100-year maximum flood height is projected to rise to more than 12 feet under the higher-emissions scenario by the end of this century. This means that many more existing buildings and properties (as well as associated infrastructure) will be at risk of being inundated. A detailed look at inundation maps for Boston based on today's 100-year floods and those projected for 2050 and 2100 provides a stark indication of the neighborhoods and infrastructure at risk. (See the text box on Boston and coastal flooding.)

Only recently have urban planners begun to come to terms with the reality that neither the ocean nor the climate is stable, and both may change rapidly over the next century. In many cases, the Northeast's city managers and coastal planners must be prepared to contend with substantial increases in the frequency and extent of major floods and the disruption these could create in an increasingly developed environment.

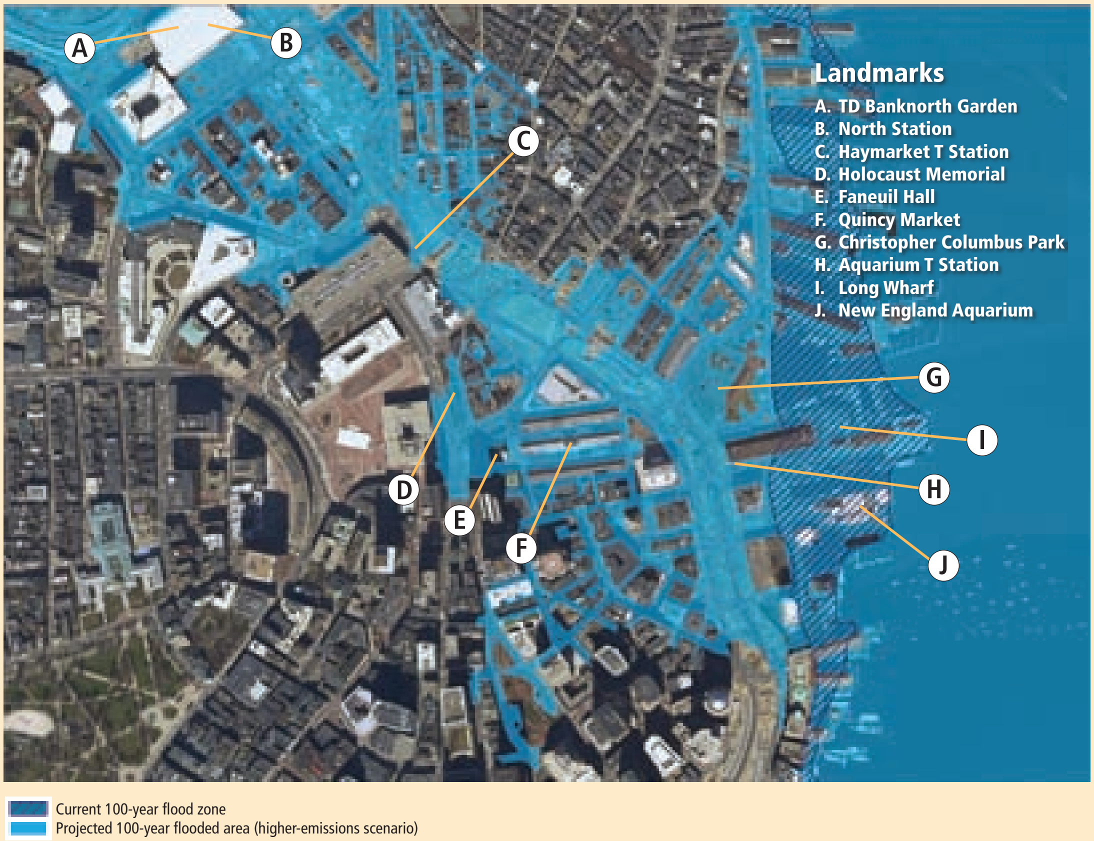
New York City, by far the region's largest urban center, provides an important example. Its Metropolitan Transit Authority subways, buses, and railroads move nearly 6 million people on an average workday, and 250 million vehicles pass through its tunnels and bridges each year.[28] The small waterfront area known as the Battery, at the southern tip of Manhattan, provides a prime example of the city's vulnerability to coastal storms. The Battery is home to such critical transportation infrastructure as F.D.R. Drive, West Street, the West Side Highway, the Port Authority Trans-Hudson (PATH) tunnels linking Manhattan

CONTINUED ON PAGE 22

Coastal Flooding in Boston: The Risks Facing Northeast Cities

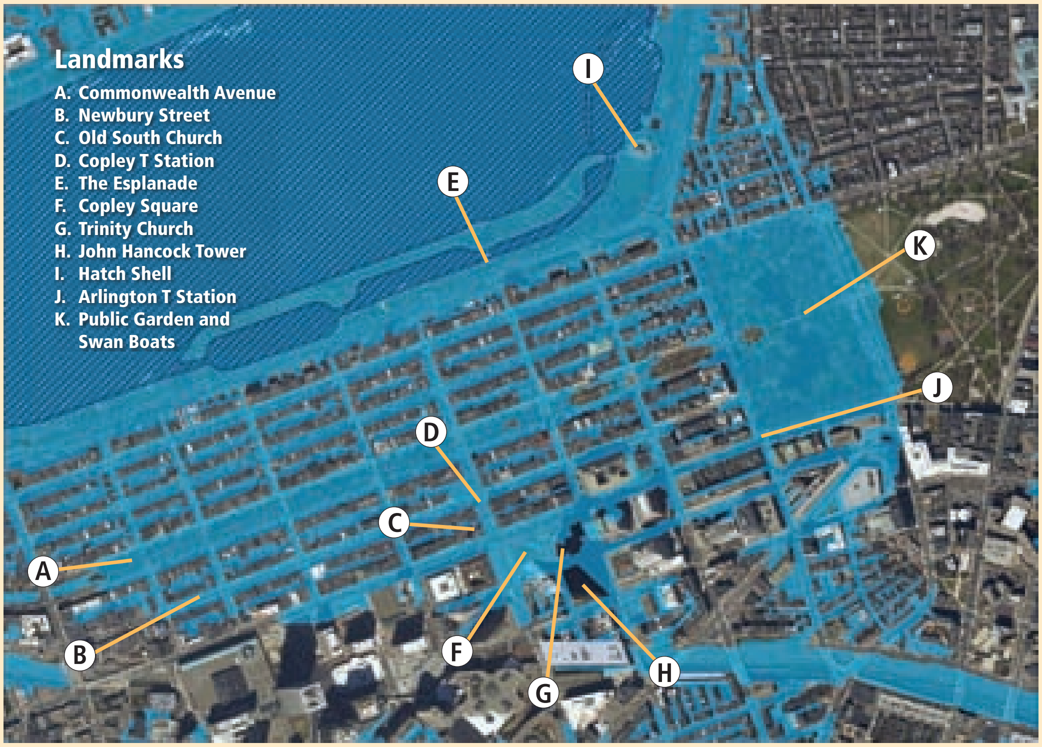
As one of the oldest U.S. cities, Boston relies on infrastructure—buildings, roads, railways, tunnels, water and sewer systems, communication systems, electric utilities, etc.—put in place over many years and under varying building codes. Though Boston has a lengthy history of protecting itself against both the sea and rivers, the extra stresses created by sea-level rise, flooding, and more extreme storm runoff can be expected to severely tax this infrastructure, threatening vulnerable neighborhoods, residents, their livelihoods, and the local economy.

- ***Coastal defenses.*** Bulkheads and seawalls protect Boston's shoreline neighborhoods from wave action and storm-related flooding. These defenses, however, vary in age and design specifications. As rising sea level creates higher and more frequent storm surges, the city's coastal defense structures will be put to more frequent and challenging tests, revealing any weaknesses and inadequacies.
- ***Buildings.*** The neighborhoods along Boston's waterfront are home to some of its most valuable

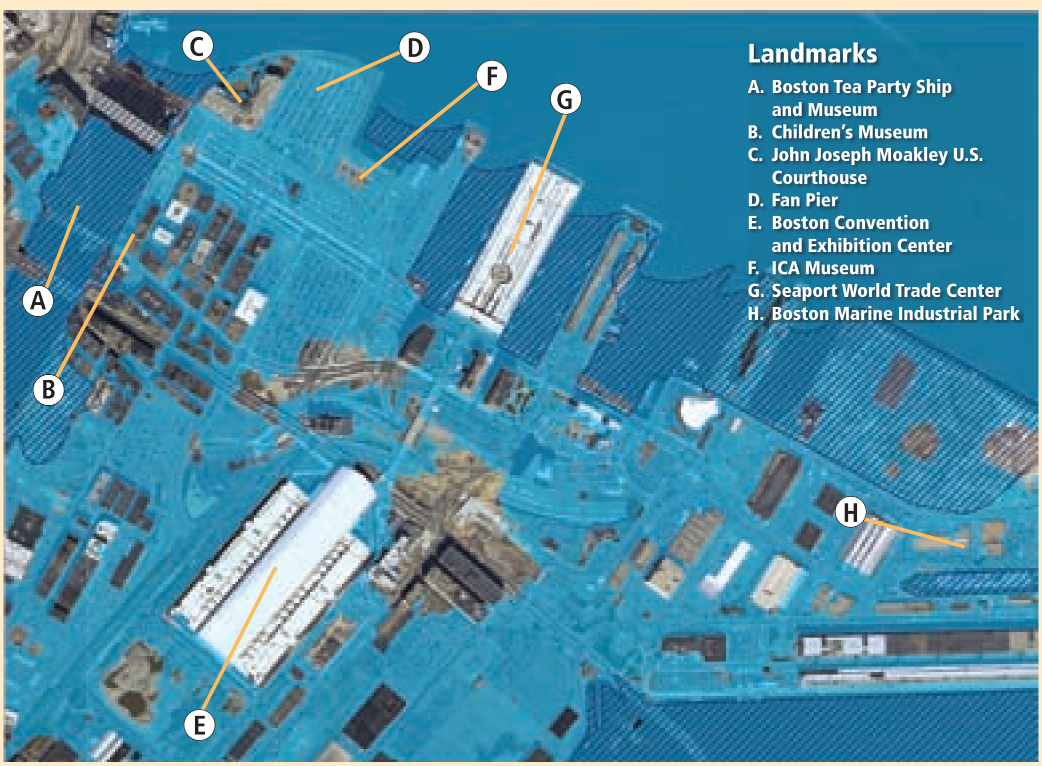


Boston: The Future 100-Year Flood under the Higher-Emissions Scenario

This image shows the current Federal Emergency Management Agency (FEMA) 100-year flood zone (hatched darker blue) as well as the extent of the projected 100-year flood zone in 2100 (lighter blue) under the higher-emissions scenario for the waterfront/Government Center area of Boston. Important Boston landmarks (such as Faneuil Hall) and transportation infrastructure currently not at great risk of flooding could witness repeated flooding in the future unless protected from such events.[29] Flood elevations under the lower-emissions scenario are roughly half a foot lower than the flooding depicted here (but still two feet higher than the current 100-year flood). See the following page for equivalent images of the Back Bay neighborhood and South Boston waterfront.



Current 100-year flood zone
Projected 100-year flooded area (higher-emissions scenario)



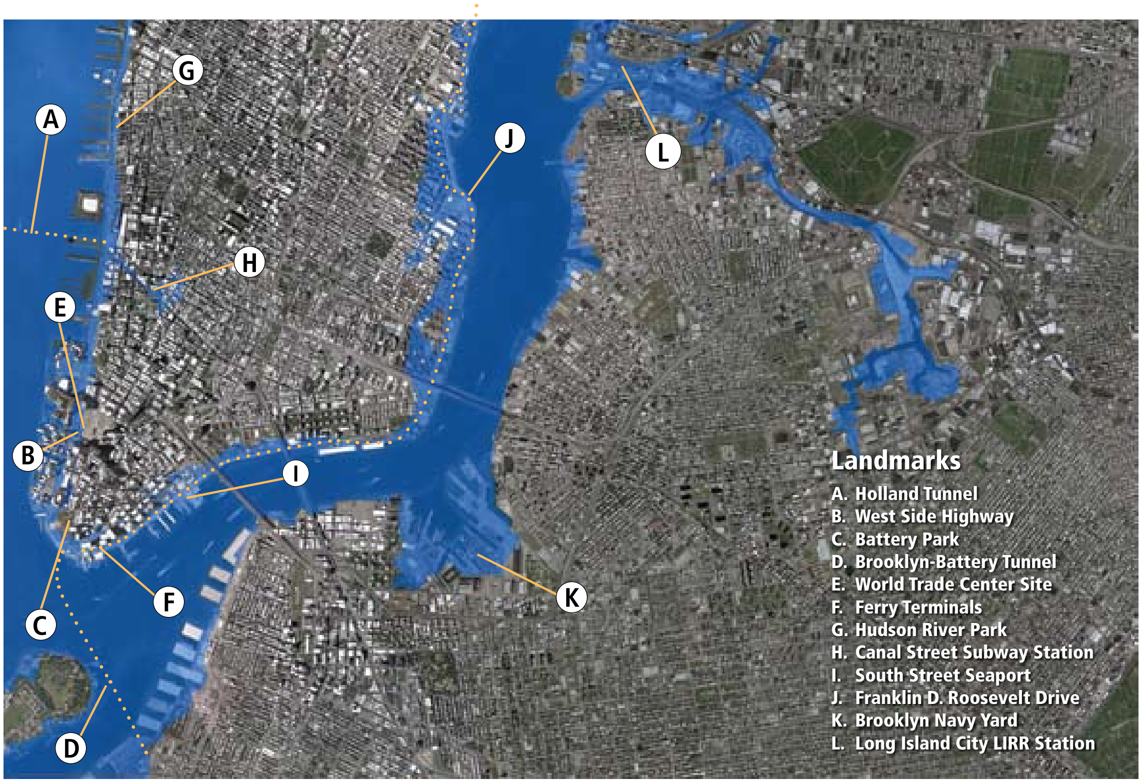
Current 100-year flood zone
Projected 100-year flooded area (higher-emissions scenario)

real estate and prized landmarks (e.g., Faneuil Hall, Long Wharf, the Moakley federal courthouse). At present, Boston's 100-year flood zone encompasses only limited areas adjacent to the waterfront. However, toward the end of the century, a 100-year flood is expected to inundate much more of the downtown area than today, affecting buildings that are not currently considered at risk from a major flood and are not constructed to withstand such conditions.

- ***Transportation.*** In 1996, heavy rains raised the level of Boston's Muddy River, flooding a tunnel entrance to the "T," the city's subway system. The damage from this flooding closed a busy subway line for several weeks and cost the city roughly $75 million.[30] While the main reason for this damage and disruption is simple—the tunnel entrance was not flood-proof[31]—it also underscores the broader vulnerability of Boston's transportation infrastructure: its subway system—the country's oldest—was not built with certain conditions in mind, including significantly higher sea levels and storm surges.[32]
- ***Sewer and stormwater systems.*** Storm surges and coastal flooding tend to peak and recede with the tides. In areas where sewers and stormwater overflow systems have adequate capacity, floodwaters can drain away relatively quickly (as opposed to the standing water that persisted in New Orleans, a city largely below sea level, following Hurricane Katrina). In Boston, floodwaters would drain back into Boston Harbor and the Charles River as tides recede. However, a 100-year coastal flood in Boston near the end of this century (which could overtop the Charles River Dam, flooding adjacent areas) has the potential to create conditions where sewer lines back up and overflow and stormwater drainage is impeded.
- ***Critical facilities.*** A functional urban center depends on an array of facilities: electric utilities and transformers, water and sewage treatment plants, hospitals, telecommunications facilities, and transportation hubs. Boston's critical facilities vary in their level of preparedness for sea-level rise and major coastal flooding. The Deer Island sewage treatment facility in Boston Harbor, for example, was built in 1992 to accommodate a two-foot rise in sea level[33]—a requirement that may remain adequate throughout this century, particularly under the lower-emissions scenario. By contrast, Logan International Airport—which, like parts of Boston, is constructed on reclaimed wetlands and thus close to sea level—could be severely affected by late-century flooding.

One recent study found that flood-related damage and associated emergency costs in the Boston metropolitan region during this century could vary widely depending on which sea-level rise scenario prevails. With roughly 1.5 feet of global sea-level rise by 2100 (an increase similar to the IPCC's projected increase under the higher-emissions scenario), the cost of cumulative damages over the course of the century was estimated at $20 billion or more;[34] with 2.8 feet of SLR by 2100—a not unreasonable projection (see the introduction to this chapter and the climate chapter)—cumulative costs rose as high as $94 billion. In comparison, without global warming and using current flood-management policies, the cumulative costs of flooding by 2100 were estimated to be about $7 billion.[35]

and New Jersey by train, and the Brooklyn-Battery auto tunnel entrance. While concrete bulkheads and a seawall protect much of the Battery, it is considered highly vulnerable to coastal flooding and has been inundated during past storms.[36,37] Flooding on F.D.R. Drive and in other parts of the city during a 1992 nor'easter, for instance, brought Manhattan's metropolitan transportation system to a near-shutdown.[38] This same storm pushed the high-water level nearly eight feet above the current mean sea level, coming within one to two feet of the critical level that would have flooded the subway and rail tunnels.[39] In 2050, the maximum elevation of New York City's 100-year flood is projected to reach 9.5 feet under either emissions scenario, and by 2100, more than 10.5 feet under the higher-emissions scenario. Thus, by the end of the century, major coastal flooding projected by the NECIA analysis threatens to disrupt the city's transportation system with increasing frequency, while 100-year floods threaten to inundate far greater expanses of the city. In recognition of its vulnerability to coastal flooding, New York City

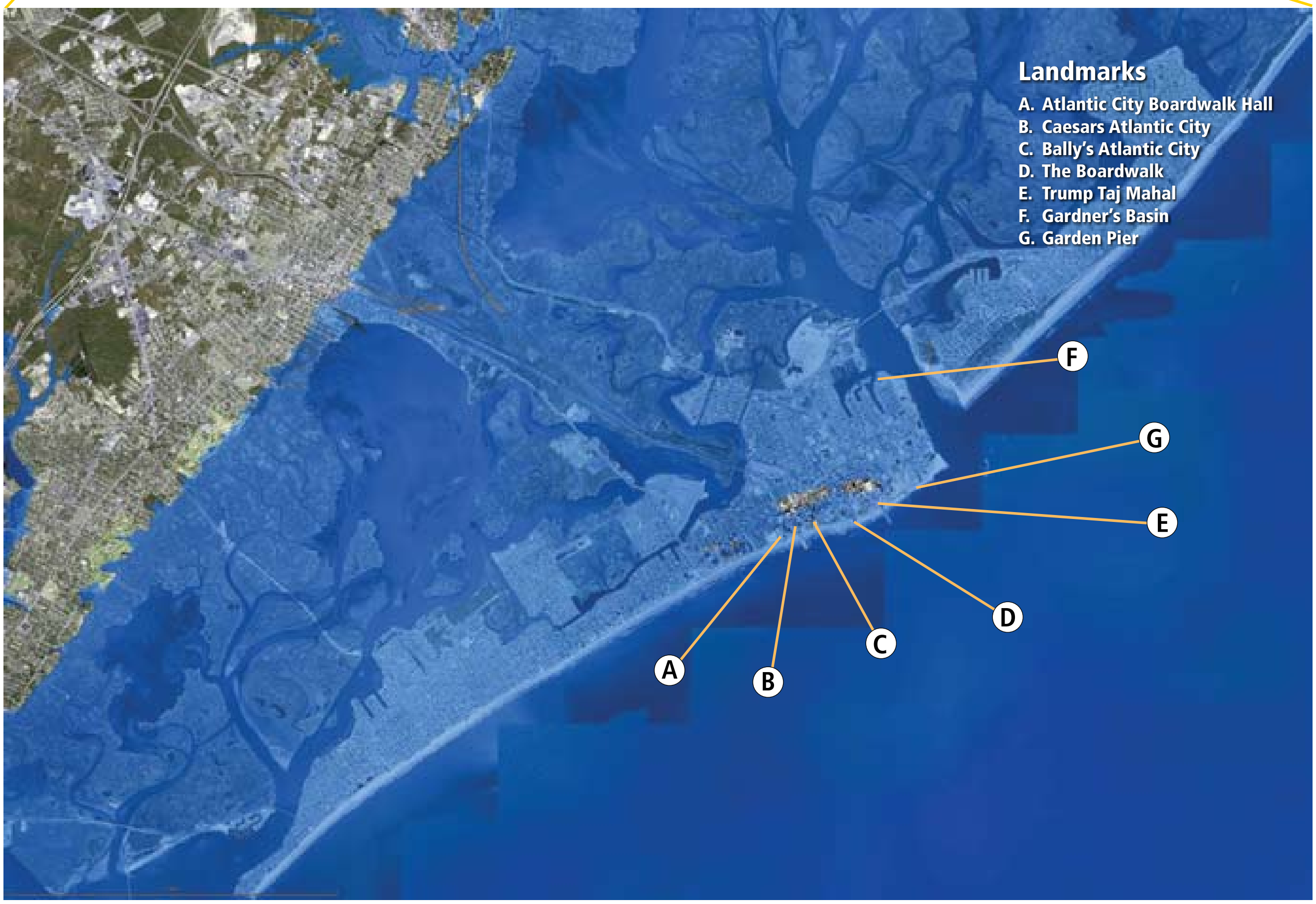


NYC: Today's 100-Year Flood Could Occur Every 10 Years under the Higher-Emissions Scenario[40]

The light blue area in these maps depicts today's FEMA 100-year flood zone for New York City (i.e., the area of the city that is expected to be flooded once every 100 years). With additional sea-level rise by 2100 under the higher-emissions scenario, this approximate area is projected to have a 10 percent chance of flooding in any given year; under the lower-emissions scenario, a 5 percent chance. As the close-up shows, critical transportation infrastructure located in the Battery could be flooded far more frequently unless protected. The 100-year flood at the end of the century (not mapped here) is projected to inundate a far larger area of New York City, especially under the higher-emissions scenario.

Atlantic City: Today's 100-Year Flood Could Become a Two-Year Flood by 2100

The top image shows the location of Atlantic City, NJ, on Absecon Island. The light blue area in the bottom image depicts today's FEMA 100-year flood zone (which extends beyond the area shown). Currently, this area has a 1 percent chance of being flooded in a given year. By 2100, this approximate area is projected to flood, on average, once every year or two under either emissions scenario, inundating high-tourist-value hotels and casinos. Under the higher-emissions scenario, the new 100-year flood height would be roughly four feet greater in 2100 than today, flooding a far greater area than the current FEMA flood zone.



is taking steps both to adapt and reduce its heat-trapping emissions.[41]

All coastal states in the Northeast have laws and programs in place that attempt to manage coastal flooding hazards. As of 2006, however, Maine was the only state in the nation to have developed and implemented shoreline regulations that take into account specific projections of sea-level rise associated with global warming. These regulations, first put in place in 1988 and revised several times since, were motivated by concerns over rapid coastal development in the late 1980s. Focusing on development in hazardous areas such as coastal sand dunes or beaches, Maine's laws restrict development within zones subject to 500-year floods and prohibit the rebuilding of structures considered to be more than 50 percent damaged by a storm (unless the owner can demonstrate that the site will remain stable in the face of a two-foot sea-level rise due to global warming over this century). Recently, Massachusetts and New York have also begun to assess the growing risks of—and options for dealing with—sea-level rise through their coastal-management programs.[42,43]

SHORELINE CHANGES

Waves, currents, and tides constantly reshape the shoreline, and as sea-level rise accelerates, these forces have the potential to dramatically alter the Northeast's coast. The severity of coastal erosion and retreat depends on local factors such as wave action and geologic substrate, but the rate of erosion is typically several orders of magnitude greater than the vertical rise in sea level itself.

As sea level continues to rise, low-lying barrier beaches will respond dynamically to wave action and erosion. Owners of beachfront property and tourism-dependent establishments or facilities, however, are invested in beaches staying put. Historical efforts to stabilize eroding shorelines typically have interfered with the natural movement of barrier islands by preventing waves from breaching or washing over the islands and depositing sediment on the landward side. Such stabilization can lead to beach and wetland loss and increase the potential for storm impacts on property and infrastructure when sea levels are higher.

Shoreline erosion is already a severe problem in many parts of the Northeast. Along the Jersey Shore, for example, the 100 miles of nearly continuous sandy beach already suffers from severe erosion exacerbated by storm damage and unbridled coastal development. New Jersey is the most densely populated state in the nation, and 60 percent of the state's people live in its coastal counties.[44] In addition, nearly 70 percent of the state's $30 billion in tourism revenues is generated in these coastal counties.[45] State and federal agencies therefore spend millions of dollars a year on "beach nourishment" projects to

Barrier Islands on the Front Line of Rising Seas

An April 2007 nor'easter cut an opening through Nauset Beach peninsula on Cape Cod. In this photo, taken a few days after the storm, the breach had grown to 150 yards. An example of the impact of such breaches can be found a short distance away on Nauset Island, where a second gap, also opened by a nor'easter (in 1987) is now a mile wide. That gap (not visible in this image) exposed the newly developed shoreline behind it to increased wave damage and erosion that eventually led to the loss of nearly a dozen homes. As sea level rises, barrier islands become increasingly vulnerable to storm overwash and breaching.

Insurers Retreat from the Coast

After Hurricane Andrew swept across southern Florida in 1992, property-insurance claims totaling four times more than any previous storm sent shock waves through the insurance industry. Some insurers went bankrupt, others raised premiums and deductibles, and some withdrew from the coastal market altogether. Now, in the wake of damaging hurricanes in 2004 and 2005 (culminating in the record-breaking losses of Hurricane Katrina), insurers are retreating not only from the Gulf Coast and Florida but the entire Eastern seaboard.[46,47]

Allstate Corporation, for example, the nation's second-largest home insurer after State Farm, first discontinued writing homeowner policies in hurricane-ravaged Florida and other Gulf Coast states. Then in 2006, Allstate announced that it was dropping coverage for thousands of homeowners along the Mid-Atlantic and Northeast coasts, including in Connecticut, New Jersey, and New York City. State Farm itself decided it would no longer write new policies for properties within a mile of the ocean (its previous cutoff was 1,000 feet). And one of the leading home insurers on Cape Cod, Hingham Mutual Group, cancelled more than 9,000 homeowner policies in 2006, arguing that its own insurance (called reinsurance) had doubled in price.[48,49,50]

Many blame this pullback on two factors: the prospect of global warming-driven increases in extreme weather events and rising sea levels, and the recent occurrence of several severe coastal storms that affected areas undergoing rampant development.[51] According to the National Hurricane Center, the population of the 18 East and Gulf Coast states rose from 66.8 million in 1980 to 86 million in 2003; by 2008, this coastal population is expected to grow to 90 million.[52] In 2004, the value of insured coastal properties in the East and Gulf Coast states totaled $6.86 trillion, including $3.7 trillion in the Northeast's seven coastal states. More than $1.9 trillion of that property is in New York alone.[53]

The combined effects of global warming and growing coastal populations create a level of risk that the insurance industry may not be able to absorb alone. One way to ensure continued and effective insurance coverage is for insurance premiums and deductibles to properly reflect the growing likelihood and extent of loss. If properly priced, insurance can (in concert with strict enforcement of building codes and other activities that minimize risk) send the right signal to those living in exposed coastal areas—i.e., that the risk of significant damages and loss is high.

Rising Seas Put Coastal Properties at Great Risk

A growing population and expensive development in coastal areas, combined with projected increases in the frequency and height of coastal floods over the next century, translate into a much greater risk of severe storm-related damage in the Northeast. The combined effect may create a level of risk that the insurance industry cannot absorb alone.

To the extent insurance and building practices do *not* adequately reflect the growing risks, state and federal governments (with the help of taxpayer dollars) could be forced to cover damages and cleanup and recovery costs. This could be done through the National Flood Insurance Program (NFIP) or state-operated Fair Access to Insurance Requirements (FAIR) plans. Some of the latter, considered by some to be "insurers of last resort," are funded by private companies while others are now backed by government-issued bonds.

While some coastal property owners have been able to replace their cancelled policies with insurance from other private insurers (although often at higher rates and with high deductibles for wind damage), many more have turned to FAIR plans, whose rates can be even higher than those of private insurers. By early 2006, more than 28 percent of the policies on Cape Cod were written under the FAIR plan, compared with four percent in 2000.[54]

Florida provides another illustration of changes that have occurred with respect to insurance against hurricane damage. Most houses in the state are covered against windstorm losses and about one-third are insured against floods under the NFIP.[55] Given its historic vulnerability, Florida has played a leading role in providing insurance and reinsurance to homeowners through myriad state-sponsored entities such as Citizens Property Insurance Corporation, which was designed to provide property insurance where it was unavailable from the regular market. In January 2007, Citizens raised insurance premiums in an effort to reflect actual risk to homeowners. This move was quickly met with strong public opposition, however. In response, the Florida legislature significantly changed Citizens, reducing its rates and greatly expanding its exposure—changes that a recent analysis suggests will encourage a large portion of Florida policyholders to switch to Citizens unless private insurers reduce their own premiums.[56] If no major hurricanes hit Florida in the near future, homeowners will likely see the lower rates as a positive. On the other hand, a major hurricane in the next several years could demonstrate that this approach is not sustainable.[57]

In the Northeast, insurance-related issues have not yet put a damper on the coastal real estate market.[58] As the nation's coastal population continues to grow, insurance-industry experts insist the solution to reducing exposure to catastrophic risks cannot rely on insurance alone but must also include reform of coastal land-use policies and stronger building codes, which currently fail to consider the impacts of global warming.[59]

replace lost sand, restoring not only the beaches' tourist appeal but also their ability to protect adjacent resort and residential communities from storm damage.[60]

Similar coastal erosion and beach loss is occurring on parts of Cape Cod. (See the Cape Cod text box.) The south shore of Nantucket Island, which has lost a total of 0.5 mile of land to the Atlantic Ocean since colonial times, is now eroding at about 15 feet a year.[61]

The U. S. Geological Survey (USGS) has calculated a coastal vulnerability index (CVI) that highlights the areas most at risk from sea-level rise, taking into account past changes in the shoreline, typical wave action, tidal range, coastal landforms, coastal geology, and sea-level history.[62]

- Areas of high vulnerability in the Northeast include most of Nantucket Island, the eastern portions of Martha's Vineyard, parts of south Cape Cod, parts of Long Island, and most of coastal New Jersey including Atlantic City.
- While the USGS does not project what areas will be affected by accelerated sea-level rise due to climate change, low-lying barrier islands can be expected to face higher storm waves that can wash over and cut inlets through the islands.[63]

In addition, the steep bluffs and coastal cliffs common along the shoreline from Massachusetts to Maine will experience increased wave attacks at their base, accelerating the pace of cliff retreat and failure. Seawalls and other stabilizing structures may slow erosion and land loss, but as sea levels rise, so will the costs and environmental impacts of such intervention (and sand replacement needed to maintain the beaches in front of these structures).

Like the shoreline, coastal salt marshes in the Northeast are already threatened by sea-level rise. Additional threats to these wetlands include rising temperatures and increasing nutrient (nitrogen and phosphorus) input from sewage-contaminated groundwater and runoff from agricultural and developed land, which stimulates algal growth that can deprive water of oxygen and kill other forms of life. Marshes serve a vital role in buffering coastal areas from the effects of waves and erosion, and provide other valuable ecological services such as filtering out nutrients and pollutants before they reach ocean waters, serving as nursery grounds for commercially important fish and shellfish, and providing habitat for waterfowl, migratory birds, and many threatened or endangered species such as piping plovers and roseate terns.

One-third of the commercial fish and shellfish species harvested off the Northeast's coast depend on estuaries and wetlands for food or protection during their juvenile or adult stages. These include such key species as lobster, clams, bay scallop, conch, winter flounder, menhaden, alewife, herring, and several species of shark.

Long Island Sound supports the most productive hard-clam fishery in the nation and is second only to Louisiana in oyster production. Both of these shellfish species are vitally dependent on wetland-based food chains. Yet Connecticut has already lost 74 percent and New York has lost 60 percent of their wetlands along the sound due to drainage, development, and shoreline retreat in response to historic sea-level rise.[65] In New Jersey, where menhaden makes up a large portion of the commercial fish catch, wetland loss is cited as one of the principal threats to that declining fishery.[66] Recreationally important species such as bluefish and striped bass also depend on wetlands to supply the small fish on which they prey, and wetland loss is believed to be partly responsible for the significant decline in bluefish populations over the past 10 years.[67]

Over the past several thousand years, marshes along the Northeast coast have managed to accumulate (or accrete) enough sediment and organic matter to maintain their elevation in the face of gradual sea-level rise. But some marshes are already changing in response to the historic acceleration in sea-level rise; low-marsh vegetation (found from sea level to the high-tide line) such as cordgrass is overtaking the high-marsh zone in some parts of New England.[68] The low-marsh zone is more productive by far in terms of plant life than the high-marsh zone, and can accrete sediment and increase its vertical elevation faster. Other salt marshes in the Northeast, however, seem not to be able to accrete fast enough to keep up with sea-level rise.

Past a certain threshold rate, rapid sea-level rise (exacerbated by land subsidence) would cause wholesale inundation and loss of marsh vegetation. This in turn will leave urbanized coastal areas more vulnerable to erosion and flooding, allow more nutrients and pollutants to contaminate coastal waters, diminish habitat for myriad bird and other animal species, and threaten populations of commercially important fish and shellfish.

The transformation of salt marshes behind barrier islands into open-water environments can also set the stage for greater wave and storm damage to the barriers themselves. This is due to the increasing volume of water flowing between the ocean and the former marsh through tidal inlets.[69,70]

Some salt marshes in the Northeast already appear to be unable to keep up with sea-level rise. Continuing land subsidence and the relatively low quantities of river-borne sediment available to salt marshes in the Northeast will eventually lead to significant loss of coastal wetlands.

Projecting Local Impacts of Sea-Level Rise

Projecting the impacts of rising sea level on specific locations is not as simple as mapping which low-lying areas will eventually be inundated. Higher ocean levels affect processes such as coastal erosion and flooding during storms; erosion reshapes the shoreline, which in turn affects where and to what extent floodwaters inundate the land during storms. Moreover, during storms, the higher sea level can combine with tides and strong winds to produce higher storm surges. Although floodwaters eventually recede, higher storm surges are likely to increase the damage from flooding even if the storms themselves do not change in frequency, intensity, or path.

Researchers have used empirical concepts and models such as the Bruun rule—an equation for calculating land loss due to sea-level rise—to predict how far any given shoreline will retreat in response to rising sea level. Many coastal planners and managers use such tools today.[64] However, the accuracy of these tools has been challenged because they fail to account for such critical factors as differences in the underlying geology of the shore and local wave action.

Quantitative projections of future shoreline change remain hampered by the innate complexity and even randomness of coastal dynamics, and by the difficulties of projecting storm frequency and intensity. The NECIA analysis used well-established methods and the best understanding of coastal processes to separately project (a) those areas that are likely to be affected by flooding from future coastal storms and (b) the types of coastal areas most at risk from shoreline changes under specific sea-level rise scenarios.

COASTAL ADAPTATION

As beaches retreat, wetlands disappear, and storm damage becomes more severe, coastal development and infrastructure will face increasing threats, regional tourism and fishing industries could suffer, and the insurance industry will increasingly be called upon to buffer the economic losses. On the other hand, loss of beach in one area may result in the shifting of sand to another beach close by, and communities and industry may be able to adapt to these changes over the long term—but not without enormous financial and social costs.

As the IPCC points out, the current level of adaptation among North American coastal communities to historic and expected sea-level rise is uneven, and readiness for increased exposure is low.[71] Options for managing climate-change risks are constrained by past development and land-use patterns as well as current coastal laws and regulations, and the expectations they have fostered among coastal property owners. Coastal managers are faced with the difficult challenge of adapting regulations to protect against increasing risks rather than historic risks. As noted above, Maine is furthest along in tackling this challenge because it has implemented shoreline regulations that take future sea-level rise into account.

The insurance industry can help distribute climate-change risks so the burden is shared by the many rather than just the few. For this industry, global warming represents both new perils and new business opportunities. (See the text box on coastal insurance.) The Northeast, being a center of the U.S. insurance industry, has an opportunity to play a leading role in shaping the industry's response to climate change.

Public education about the region's changing exposure to risk will need to be increased and linked to strict enforcement of building codes and land-use regulations, may require mandatory insurance coverage, and involve other activities that minimize risk. Continued and enhanced access to insurance, as well as long-term mitigation loans and subsidies, will play a critical role in protecting particularly vulnerable people living in high-risk areas. Moreover, the region's tremendous scientific and technical capacity needs to be applied to the task of improving coastal risk management.

Can Coastal Wetlands Keep Pace with Rising Seas?

If sea level rises faster than wetlands can grow vertically (by "accreting" sediment and organic material) significant portions of this already threatened habitat would be lost. The wetlands near Shorebird Point in Biddeford, ME (pictured here), for example, receive only limited quantities of river-borne sediment and thus are highly vulnerable to becoming permanently inundated under the projected rates of sea-level rise.

Changes in Storm Patterns

The storms that most commonly menace the Northeast are the winter storms known as nor'easters, named for their fierce winds that typically sweep toward the coast from the northeast. Nor'easters are a frequent phenomenon from fall through spring (October to April), but only the most powerful make headlines, unleashing heavy snow or drenching rain and sometimes bringing traffic, schools, and commerce to a halt. Some nor'easters even batter the region with hurricane-force winds and surf, causing severe beach erosion and coastal flooding that destroys property and threatens lives. Some of the most infamous include the Ash Wednesday Storm of 1962, the Blizzard of 1978, the Perfect Storm (or Halloween Storm) of 1991, and the Storm of the Century in 1993.

Strong nor'easters develop when two different types of air mass collide. One is a low-pressure system spawned by warm air and moisture rising from the Gulf Stream in the Gulf of Mexico or off of Florida; its counter-clockwise circulation generates strong northeasterly winds as the storm follows the jet stream north along the Atlantic seaboard. The second air mass is a high-pressure system that extends south from the Canadian Arctic, with clockwise winds driving cold air into the northeastern United States. When the two systems interact near the coast, the combination of strong winds, cold air, and moisture can generate heavy snow or ice storms, battering coastal and inland areas.

The intensity and frequency of nor'easters is driven in complex ways by oceanic and atmospheric conditions over a very large area. Because global warming will affect both the ocean and atmosphere, the NECIA analysis assessed potential impacts of projected climate-driven changes on the frequency and timing of nor'easters striking the Northeast. Additional changes in intensity and track were not assessed specifically. However, the storm track of extratropical low-pressure systems such as nor'easters has shifted northward beginning in the 1970s. They now strike New England more frequently, and with

A Nor'easter Batters the Coast

The Northeast has weathered hurricanes, nor'easters, and associated flooding throughout its history. With global warming, coastal communities such as Winthrop, MA, shown here, face the prospect of increased damage from coastal flooding associated with these storms.

greater intensity, while fewer affect the Mid-Atlantic states.[72,73]

Currently, an average of 10 or 11 serious storms hit the East Coast each winter.[74] During November and December, 70 to 80 percent of these storms move far enough north to affect the Northeast; in late winter (January, February, and March), however, only 50 to 70 percent reach the Northeast. Climate models suggest little change in storm frequency this century, but by century's end under the higher-emissions scenario, between 5 and 15 percent more late-winter storms will move far enough north to affect the Northeast (about one additional late-winter storm per year). If lower emissions prevail, little change is projected in the number of nor'easters that strike the region.

Although rarer than nor'easters, the Northeast is also occasionally affected by tropical storms and hurricanes that form in the Atlantic during the summer and fall. There is growing evidence that the *intensity* of tropical storms and hurricanes has already been increasing;[75,76,77] debate continues over a definitive link between global warming and increased hurricane *frequency*.[78,79,80,81,82] It is clear that observed ocean warming—a key condition for the formation and strengthening of hurricanes—cannot be explained by natural cycles alone. Recent studies suggest that increased hurricane intensity, as exemplified by the rising number of category 4 and 5 hurricanes, is driven at least in part by global warming.[83,84,85]

Atlantic hurricanes frequently follow a path toward the Northeast, yet landfall in this region is historically rare. Even if the intensity or frequency of hurricanes and nor'easters striking the region does not increase, the combination of accelerated sea-level rise and continuing coastal development will substantially increase the risk of major damage along the Northeast's coast when these storms do strike.

Communities Especially Vulnerable to Change

By century's end an increasing number of late-winter storms could move far enough north to affect the Northeast. This means exposed coastal wetlands and developments such as that visible on this stretch of Long Island shoreline could face additional potentially damaging storms each year.

CHAPTER THREE

Marine Impacts

KEY FINDINGS

- **As ocean temperatures continue to rise, the range of suitable habitat in the Northeast for many commercially important fish and shellfish species such as cod and lobster is projected to shift northward.**
- **Cod are expected to disappear from the region's waters south of Cape Cod during this century, under either emissions scenario.**
- **Waters around Georges Bank are expected to approach the maximum temperature threshold for cod under the higher-emissions scenario during this century, potentially forcing cod to cooler waters, reducing cod productivity, and further challenging the sustainability of the Northeast's cod fishery.**
- **The lobster fisheries of Long Island Sound and the nearshore waters off Rhode Island and the south coast of Cape Cod are also expected to experience significant decline by mid-century.**
- **Warming in the region's colder northern waters (particularly the eastern Gulf of Maine) may actually boost lobster productivity; they may also become more hospitable to "lobster shell disease."**

BACKGROUND

For centuries, since European seafarers first encountered cod, whales, and other biological riches in the uniquely productive waters of the western North Atlantic, fishing has played an integral role in shaping the culture, character, and livelihood of communities along the coast. The Northeast's continental shelf comprises three distinct ocean areas: the deep waters of the Gulf of Maine; the large, comparatively shallow and highly productive Georges Bank to the south and east; and the broad and gently sloping shelf of the northern Mid-Atlantic Bight (which, in its entirety, extends from Cape Cod south to Cape Hatteras, NC). These waters are also spanned by the steepest sea-surface temperature gradient on the planet, which creates both warmer- and colder-water marine environments and contributes to their exceptional productivity.

Today, despite the overexploitation of many fish species, increasing coastal development, pollution, and other pressures, fishing remains a staple of the Northeast's economy, and iconic species such as cod and lobster are a treasured part of the region's identity and appeal. In 2003 the direct and indirect economic contributions of commercial fishing to the region—plus Delaware, Maryland, and Virginia—totaled $10.4 billion per year.[1] In 2004 dockside revenues from commercial catches of groundfish such as cod and flounder exceeded $1.2 billion; shellfish totaled just over $900 million, most of it from lobsters ($366 million) and sea scallops ($319 million).[2]

From fishermen to wholesalers and processors, the commercial seafood industry supported more than 76,500 jobs in the Northeast in 2004 and put more than 2,500 vessels to sea under federal fishing permits.[3] Many thousands of smaller vessels not requiring federal permits also operate within state waters. In Maine, for example, some 4,000 boats fished for lobster in 2004.[4] Recreational fisheries also provide substantial economic benefits in the form of angler expenditures and employment opportunities.

New Challenges Loom for Fishing Communities

Warming waters may eliminate cod and lobster fisheries south of Cape Cod, affecting the Northeast's more southerly fishing ports, such as Northport, NY (pictured here). These communities may be able to capitalize on warm-water species expanding their range northward, but much uncertainty remains as to which species will move into the region.

In 2005 nearly 25 million recreational fishing trips were made along the coast from Maine to Virginia.

Global warming will probably be accompanied by a northward shift of warmer-water species, but it is not clear what the local production of those species would be during such a transition. Other species are already at the southern end of their range in northeastern U.S. waters. Commercial fish and shellfish including cod, lobster, sea scallops, and Gulf of Maine shrimp have water-temperature thresholds that define the conditions within which they can successfully reproduce, grow, and survive to "recruitment" (i.e., when they are large enough to harvest). Sizable stocks of these species are not typically found in waters that fail to meet such thermal requirements. Therefore, the warming projected over the course of this century may lead to a loss of traditional, high-value species in some areas, while lobster populations in much of the Gulf of Maine may benefit. Global warming may also drive complex shifts in ocean circulation, nutrient supplies, plankton production, and other factors that shape marine ecosystems in ways that are difficult to predict.

OCEAN DYNAMICS

The waters of the Northeast's continental shelf, which extends more than 125 miles offshore in some areas, are influenced by large-scale circulation patterns in the western North Atlantic. Cold and relatively fresher water flows south from the Labrador Sea and beyond, while warm, saltier water is carried north by the Gulf Stream. These two current systems create a zone of steep temperature gradients in the region and, together with fresh water flowing in from the region's rivers, help determine temperature, salinity, nutrient levels, plankton production, and fish distribution and abundance across various parts of the continental shelf.

TABLE 1: Annual Commercial Landings by State in 2005 (in millions of dollars)[5]

	CT	NJ	MA	ME	NH	NY	RI
Clams	16.1	33.1	18.3	17.8	-	21.4	5.6
Cod	-	-	15.7	2.8	1.9	-	0.3
Flounder	1.2	5.1	28.8	4.4	0.4	4.2	7.6
Goosefish	0.6	4.4	21.5	6.2	1.5	2.0	4.7
Hake	2.4	0.2	3.7	2.9	0.3	2.3	2
Lobster	3.8	2.0	49.4	319.1	14.4	4.4	23.0
Sea scallops	9.8	88.5	227.1	0.2	0.5	3.6	13.3
Shrimp	-	-	-	2.0	0.3	-	-
Squid	1.5	2.8	1.7	-	-	6.1	17
All species	37.6	159.0	426.9	393.2	22.2	56.5	91.8

In turn, climate and atmospheric conditions strongly influence the position and strength of ocean currents, and thus the physical and biological conditions of the Northeast's waters. For example, the North Atlantic Oscillation (NAO), a pattern of variability in the relative strengths of two atmospheric pressure centers over the North Atlantic, is currently in a positive phase. In the Gulf of Maine, this has been correlated with both northward shifts in the position of the warm-water Gulf Stream and increases in volumes of cold-water transport in the Labrador Current.[6] A positive NAO is projected to dominate (or have a strong presence) over the next 50 to 100 years—especially in winter and under the higher-emissions scenario—according to many scientific models, including those used in our analysis. NAO conditions in turn drive a cascade of impacts on marine ecosystems (see below).

Changes in remote regions of the North Atlantic may also influence conditions in northeastern U.S. waters. During the 1990s, for example, the waters of the Labrador Sea became markedly fresher, especially on the continental shelf; at the same time, the Gulf of Maine also experienced a widespread decrease in salinity—a change that was not linked to increased local rainfall or river inflow. These two events were likely related. Since most climate-change scenarios project the Labrador Sea and other higher-latitude waters to become fresher as a result of increased ice melt, conditions in the Gulf of Maine during the 1990s may be a preview of the future impact of global warming.

Some changes in Arctic climate and the strength of different currents that exchange waters between the Arctic Ocean and the North Atlantic have been linked to a shift in plankton abundance in the Gulf of Maine and on Georges Bank, with cascading effects for marine life in these waters.[7] Present scientific models, however, cannot project changes in these ocean current systems.

Seasonal shifts and year-to-year variability in weather patterns also strongly affect temperature, salinity, and other conditions on the Northeast's continental shelf. Projected change in these patterns, driven by global warming, can be expected to further influence Northeast waters, albeit in ways that science is just beginning to understand. Most of these waters are "stratified" during the warm months (i.e., surface waters warm and become more buoyant, trapping a layer of cooler, denser water below),[8] which eventually leads to nutrient limitations at the surface because this layer does not mix with the nutrient-rich layer beneath. In the fall the surface layer cools and sinks, and more frequent strong winds increase the mixing of top and bottom waters. Bottom waters are therefore generally warmest in late fall. Cooling and mixing continue during the winter months, but the minimum temperature, maximum depth of mixing, and degree of nutrient replenishment of surface waters can vary substantially from year to year.

Commercial fish and shellfish, including cod and lobster, have water-temperature thresholds that define the conditions within which they can successfully reproduce, survive, and grow to harvestable size.

The timing of stratification and de-stratification is affected by weather, including cloud cover (which reduces solar heating of surface waters), wind, air temperature, and freshwater input (from both local and remote sources). Even in winter, factors as subtle as cloud cover (which also reduces the sunlight needed for photosynthesis)

A Rare Right Whale Mother and Calf

Small pods of highly endangered North Atlantic right whales *(Eubalaena glacialis)* ply the Northeast's waters in summer. The number of right whale calves born in a given year (into a total population of roughly 300) has been related to climate shifts that influence the abundance of the whales' favorite food, *Calanus finmarchicus.*[9,10] Recovery efforts for this species will likely be influenced by the effects of global warming on the abundance of this food resource.

and wind can affect algal production in shallow waters near the shore and over Georges Bank. Changes in the composition and annual cycles of plankton communities can affect many organisms that feed on plankton throughout their lives, including some fish, whales, and birds. Such changes may be as important—or more important—than those caused by temperature alone.

SURFACE AND BOTTOM WATER TEMPERATURES

Because water temperature plays a dominant role in shaping marine ecosystems, much can be learned by examining projected changes in surface and bottom water temperatures driven by global warming. An ideal assessment of global warming's potential impacts on marine systems would take into account the complex factors mentioned above: climate-driven shifts in circulation patterns and stratification that affect temperature, nutrient distribution, plankton productivity, the transport of lobster and other species in their larval stages, and ultimately the Northeast's fisheries. However, such an assessment requires the coupling of results from coarse-scale climate models designed to project changes over large areas with much finer-scale models of ocean dynamics.

The water-temperature projections outlined below are the result of a demonstration of such a coupling. It must be noted that this type of coupled-model analysis remains at an early stage of development. Thus, although the projections attempt to take into account many aspects of regional climate that interact to shape local ocean conditions, the NECIA analysis has focused on temperature's importance as a habitat variable for many species.

Sea-surface temperatures along the Northeast's coast have risen more than 1°F over the course of the twentieth century, and are projected to rise up to another 6°F to 8°F under the higher-emissions scenario and 4°F to 5°F under the lower-emissions scenario by late this century (the increases vary for different portions of the Northeast's continental shelf).[11,12] The NECIA analysis of bottom water temperatures for the northern Mid-Atlantic Bight, Georges Bank, and the western and eastern portions of the Gulf of Maine[13,14] shows that the higher- and lower-emissions scenarios produce significantly different temperature increases (Table 2).

- Under the higher-emissions scenario, bottom temperature increases are projected to be substantially greater along the southernmost part of the Northeast's coast. By the 2080s, for example, increases in spring bottom temperatures range from 7°F in the northern Mid-Atlantic Bight to 4°F in the Gulf of Maine.
- Under the lower-emissions scenario, increases in spring bottom temperatures are more consistent across the region and not as severe: 2°F in the northern Mid-Atlantic Bight, 2°F on Georges Bank, and 2°F in the Gulf of Maine. Autumn increases are projected to be slightly greater.

The potential effects of these rising temperatures on two of the Northeast's most economically important species—cod and lobster—are examined below. Although not explicitly considered here, the effects on other species (e.g., the endangered right whale, Gulf of Maine shrimp, herring, plankton species vital to the marine food web) and the region's burgeoning fish and shellfish farming operations also warrant scrutiny.

COD

Atlantic cod was the lure that first drew European fishing fleets to the Northeast, and cod has remained a staple of the region's commercial fishery since the seventeenth century. Early in that era, an English ship captain christened Cape Cod in honor of the fish

TABLE 2: Projected Increases in Bottom Water Temperature, 2080–2084 Relative to the Historic Average (1970-2000)[15]

		Northern Mid-Atlantic Bight	Georges Bank	Western Gulf of Maine	Eastern Gulf of Maine
Spring	Lower Emissions	2°F	2°F	2°F	2°F
	Higher Emissions	7°F	6°F	4°F	4°F
Fall	Lower Emissions	2°F	2°F	3°F	2°F
	Higher Emissions	5°F	6°F	4°F	4°F

Gloucester Fishing Trawlers Await Their Next Trip

Ship-shape vessels docked in Gloucester, MA, belie uncertainty about the future productivity of Northeast waters, particularly the storied fishing grounds of Georges Bank. Despite dramatic declines in cod populations in recent decades, Massachusetts still lands roughly $15 million in cod annually, leading other states by a wide margin. Rising ocean temperatures, however, threaten Georges Bank cod.

his crew hauled up in such abundance, and the cod trade became such an important part of the region's heritage and prosperity that a carving known as "the Sacred Cod" has hung in the Massachusetts State House since the eighteenth century. Recent depletion of cod and other groundfish stocks, however, has gravely diminished the value of the fishery and undermined the traditional economy of historic fishing villages such as Gloucester and New Bedford.

Landings of cod in the Northeast have declined substantially since 1995 with the collapse of groundfish stocks (cod, haddock, and flounder) on Georges Bank and the closure of the fishery on large portions of the bank and the southern New England shelf. The 14-million-pound cod catch in the Northeast brought in an estimated $21 million dollars in 2005. Massachusetts remains the dominant cod-producing state, with landings derived from both the Gulf of Maine and Georges Bank. The state's 10.5-million-pound cod landings had a dockside value of nearly $16 million in 2004, substantially below historical levels yet still in the state's top five catches in terms of overall landings value.[16]

The decline in cod landings in the 1990s has been firmly linked to over-harvesting, yet environmental conditions clearly played a supporting role. Cod populations off the northeastern coast occupy the southern extent of the species range in the northwestern Atlantic. Over the past century, cod landings in the Gulf of Maine and on Georges Bank have undergone large-scale fluctuations, and periods of low landings have corresponded with periods of high water temperatures (along with other factors). For example, a comparison of the distribution and abundance of cod in the region during the relatively cold period from 1965 to 1969 and the warm period from 2000 to 2004 indicates that cod were more widely distributed in the colder period than at present. Thus, global warming can be expected to continue altering the distribution and abundance of cod in northeastern waters.

Effects of water temperature on cod

Many stages in the cod life cycle are influenced by temperature, including spawning and feeding behavior in adults, survival and development of eggs and larvae, and growth and survival of young cod. Cod populations throughout the North Atlantic are adapted to a wide range of seasonal temperatures, including mean annual bottom temperatures ranging from 36°F to 54°F. This suggests that a maximum temperature of 54°F represents the threshold of thermally suitable habitat for cod and the practical limit of cod distribution.[17,18]

Temperature greatly influences both the location and timing of spawning, which in turn affects the subsequent growth and survival of young cod.[19] Studies indicate that increases in mean annual

Emerging Threats to the Northeast's Marine Ecosystems

Shellfish diseases. In the early 1990s, lobstermen in Rhode Island began to notice small black spots on the shells of many lobsters they pulled from their traps. The bacterial condition became known as "lobster-shell disease," and the shells of infected lobsters eventually become too grotesquely scarred for sale on the lucrative live market. By 2005, the disease had crippled Rhode Island's relatively small lobster industry, helped drive a precipitous drop in lobstering in the waters south of Cape Cod, and provoked Congress to appropriate federal research funds to try to keep the disease from spreading beyond a few infected sites in Maine, home of the nation's largest lobster fishery.[20,21] By 2006, lobster-shell disease had expanded into Cape Cod Bay, Boston Harbor, and the North Shore of Massachusetts.[22]

The cause of lobster-shell disease spread remains something of a mystery, but scientists strongly suspect that warmer water temperatures are helping to make lobsters more vulnerable to the bacteria that invade and destroy their shells.[23] Other conditions afflicting lobsters at the southern end of their habitat range also appear to be linked to chronic exposure to warm temperatures. For example, unusually high temperatures in Long Island Sound in the summer of 1999 apparently set the stage for a record lobster die-off; many of the lobsters succumbed to parasitic paramoebiasis. Another condition called calcinosis severely affects the blood chemistry of lobsters living in stressfully warm water.[24]

Lobster-Shell Disease Moves Northward

Lobster-shell disease, which renders lobsters like the one pictured here unmarketable, spread northward into Massachusetts and Maine waters in 2006. With rising temperatures, Maine's lobster fishery may grow while other states experience losses, but lobster-shell disease may expand as well.

Rising water temperatures also appear to facilitate the spread of afflictions in mollusks. An oyster disease called Dermo, for instance, has moved from Chesapeake Bay north to Long Island Sound over the past 20 years. Such diseases are only one of several threats to the Northeast's marine ecosystems that may become more prevalent as global warming alters the oceans.

Red tides. Commonly categorized as harmful algal blooms or HABs, red tides are a growing problem in nearly all U.S. coastal waters. The major human contribution to these blooms (which can cause paralysis in people who eat affected shellfish) is thought to be nutrient-enriched runoff from sewage and fertilizers, but global warming may also be creating coastal ocean conditions that favor the small percentage of harmful algal species, increasing the intensity, duration, and extent of their blooms.

In 2005, the most widespread and intense bloom of toxic red tide algae in more than three decades brought shellfish harvests from Maine to Martha's Vineyard to a halt for more than a month, costing the fisheries of Maine and Massachusetts alone $11 million in lost sales.[25,26] Researchers speculated that elevated amounts of spring rain and snowmelt followed by two uncommon May nor'easters set the stage for the unusually large bloom of *Alexandrium fundyense* responsible for the red tide.[27,28] Among the conditions that initiate and sustain HABs, climate variables such as temperature, precipitation and runoff, winds, and storms play a central role, but one that is not yet fully understood.

Invasive species. Many planktonic species, including potentially toxic algae, are transported around the world in ships' ballast water and discharged into coastal waters far from their native habitats. Others are introduced unintentionally during the movement

Shellfish Bed Closures

The underlying cause of harmful algal blooms in ocean waters is complex, but their impact on the Northeast is plain: closure of shellfishing grounds and beaches, and the significant economic losses that result from such closures. By creating ocean conditions favorable to algal blooms, global warming may make matters worse.

of oysters and other shellfish for aquaculture.[29,30,31] Among the exotic and potentially harmful marine species already spreading along the Northeast's coast are omnivorous green crabs, Asian shore crabs, and a Japanese green alga (*Codium fragile tomentosoides*) that blankets large areas of shallow waters in the Gulf of Maine.[32]

In 2003, researchers spotted an invasive tunicate or sea squirt (*Didemnum sp.*) on Georges Bank. These colonial animals have no known predators and reproduce rapidly, forming dense mats that foul ships' hulls, shellfish beds, and aquaculture facilities. Researchers fear that spreading sea squirt mats may literally seal off the gravel bottom of Georges Bank, preventing fish from feeding on benthic worms and crustaceans and blocking the settlement of larval sea scallops and other species.[33,34]

As the Northeast's waters warm, other exotic species that once found these waters inhospitable may be able to reproduce and spread, affecting marine ecosystems and economic activities in unknown ways.

water temperatures above 47ºF will lead to a decline in growth, survival, and recruitment.[35,36]

The northern Mid-Atlantic Bight

Maximum temperature threshold:

- These waters are currently marginal habitat for cod. Cod landings in New Jersey and Rhode Island represent less than 1 percent of the regional total.[37]
- Under the higher-emissions scenario the maximum temperature threshold of 54ºF for suitable cod habitat is likely to be surpassed by late-century, which suggests that cod will likely disappear from the waters south of Cape Cod.
- Even under the lower-emissions scenario a significant loss of suitable habitat is anticipated, and redistribution of cod to cooler regions can be expected. This shift in distribution may not have a severe economic impact given the current size of the fishery, but it could result in a loss of genetic diversity and other marine ecosystem changes.

Recruitment temperature threshold:

- Water temperatures already exceed the 47ºF threshold for growth and survival of young cod in this part of the Northeast, which has historically supported small spawning populations.

Georges Bank

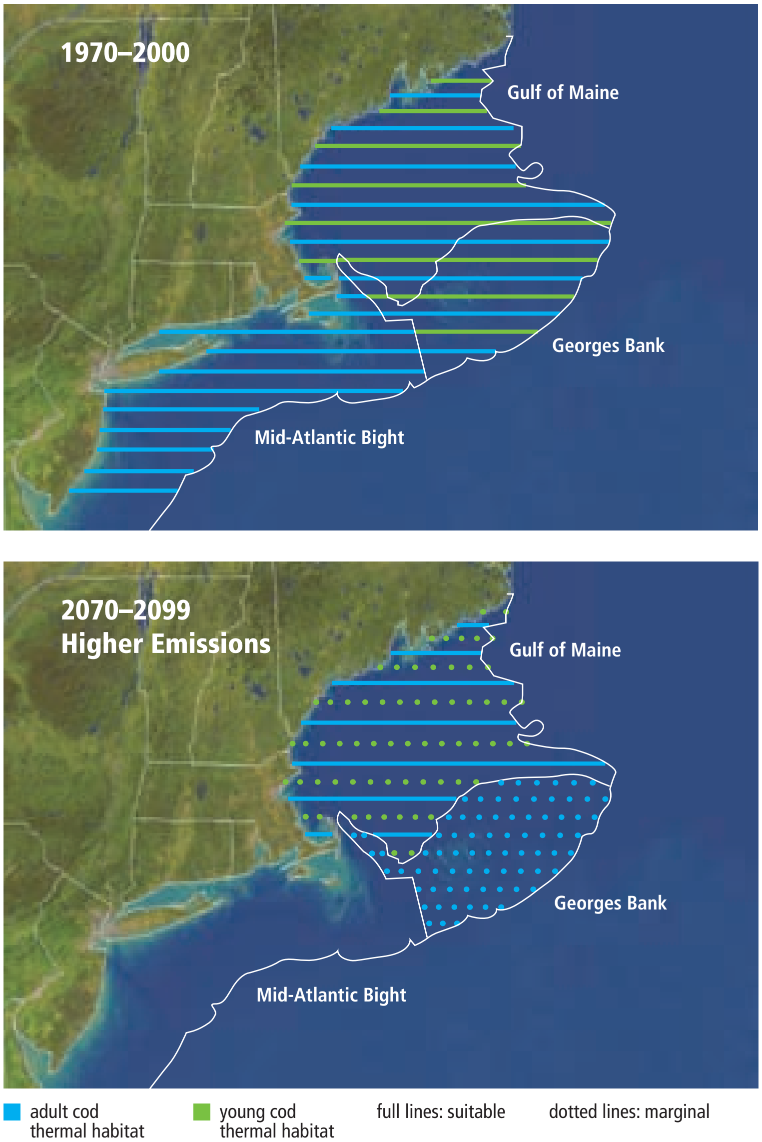
Maximum temperature threshold:

- Under the higher-emissions scenario the mean annual bottom temperature in these waters could increase as much as 7ºF by late-century, approaching the 54ºF maximum temperature threshold for adult cod. This would render these storied fishing grounds—historically the Northeast's major cod-producing region—vulnerable to substantial loss of suitable cod habitat.[38] Under the lower-emissions scenario, this threshold is not expected to be exceeded this century.

Recruitment temperature threshold:

- Current conditions in these highly productive waters are already at the 47ºF threshold for cod recruitment, indicating that a decline in production and yield can be expected as temperatures increase.[39]
- Temperatures are likely to exceed the threshold for growth and survival of young cod under either emissions scenario during this century. This would lead to declining productivity and recovery potential across a substantial part

FIGURE 5: Emissions Choices May Redefine Water Temperatures Suitable for Cod



In the waters off of the Northeast states, cod are currently at the southern edge of their favored temperature range, or suitable thermal habitat. Waters that historically provide suitable temperatures for adult and young cod (bottom temperatures less than 54˚F and 47˚F, respectively) are illustrated in the top map, while the bottom map shows changes in this area by late-century under the higher-emissions scenario. Historically productive Georges Bank is expected to no longer support the "recruitment" (growth and survival to harvestable size) of young cod and to be only marginally suitable for adult cod. The Gulf of Maine is expected to continue to support adult cod throughout the century, but the warmer waters would hinder recruitment.

of the Northeast's continental shelf. In other words, even if lower emissions prevail and Georges Bank remains suitable for adult cod, some loss in yield and productivity can be expected as the region becomes less suitable for the spawning and survival of young cod.

The Gulf of Maine

Maximum temperature threshold:

- Mean annual bottom temperatures in these waters would need to increase 9ºF to exceed the 54ºF threshold for suitable cod habitat; such an increase is not projected during this century under either emissions scenario.[40]

Recruitment temperature threshold:

- However, historical patterns of recruitment as a function of temperature in these waters indicate that a loss in cod recruitment and yield can be expected even under the lower-emissions scenario. More dramatic losses can be expected under the higher-emissions scenario.

Water temperature can also affect the survival of young cod indirectly by altering the availability of suitable food supplies at critical life stages. For example, the timing of reproduction in *Calanus finmarchicus*, a tiny crustacean that serves as a major food source for young cod, is highly temperature dependent. It may vary by as much as six weeks between cold and warm years, leading to a mismatch in the timing of peak populations of young cod and their prey.

How other climate-related changes in the marine system will affect cod remains largely unknown. Successful recruitment, for example, depends on whether wind and currents distribute larval cod into areas with suitable habitat and food supplies (or keep them in such areas). NAO conditions have also been linked to recruitment success in cod, although the impact differs between locations.[41]

This means that ongoing recovery of cod stocks from their current levels will be highly dependent on environmental conditions as well as fishery policies. Interestingly, efforts to restore cod stocks in northeastern waters during the past decade of favorable NAO conditions (by reducing the allowable harvest) have achieved only marginal success.

Despite the uncertainties, conditions on Georges Bank are likely to change significantly over this century as temperatures rise, and the fate of the Northeast's cod industry hangs in the balance. This huge shoal—larger than the state of Massachusetts—is uniquely suited to the life cycle of cod. In its shallow, sunlit waters at the intersection of the warm Gulf Stream and the cold, nutrient-rich Labrador Current, phytoplankton (algae) grow three times faster than in other continental shelf waters. Zooplankton feast on the phytoplankton, and cod larvae feast on the zooplankton. Winds, tides, and other forces result in a clockwise circulation around Georges Bank that keeps cod eggs and larvae within these rich waters.[42] As cod are driven north by ocean warming, it is unclear whether this species will be able to find another location as well suited to its life cycle. Fishermen may be able to offset some cod losses in the southern part of the region if subtropical species in the Mid-Atlantic Bight (such as weakfish, spot, and drum) increase in abundance, but global warming will undoubtedly bring added uncertainty to the fishing industry—particularly under the higher-emissions scenario.

LOBSTER

The American lobster is one of the most valuable commercial catches in the Northeast and one of the region's most recognized symbols. Indeed, lobsters are almost synonymous with the state of Maine, which not only lands more than half of the annual U.S. lobster catch but also depends on the lobster as a key attraction for the tourists who flock to the state's fishing villages to dine at its roadside shacks and waterfront restaurants.

Lobster landings have increased dramatically across the Northeast over the past three decades, though not uniformly. Catches in the southern part of the region, for example, peaked in the mid-1990s and have since declined sharply, beginning with a 1997 die-off in Rhode Island and Buzzards Bay associated with the onset of shell disease, and accelerated by a 1999 lobster die-off in Long Island Sound. By contrast, Maine has seen strong and sustained growth in landings, hauling in more than 70 million pounds of lobster—worth $311 million—in 2005 (compared with an average of about 25 million pounds half a century ago).[43,44] With lobster recruitment rates and market prices high at present, many fishermen in Maine have switched from groundfish to lobster despite the required investment in different boats and gear. In sharp contrast to the misfortunes of the groundfish industry, the record lobster hauls have brought new prosperity to lobstermen, their families, and coastal communities—communities now highly and precariously dependent on sustained lobster landings.

Lobster's geographic range extends across one of the North Atlantic's steepest north-south temperature gradients, from southern New England (where the maximum summer sea-surface temperature has historically approached 80°F) to the mouth of Canada's Bay of Fundy (where the summer maximum has historically reached only about 54°F).[45] The southern limit of lobster along the Northeast's coast is Long Island and northern New Jersey; south of that, lobsters are increasingly restricted to deeper, cooler waters at the edge of the continental shelf off Virginia and North Carolina. At the northern limit of its range in Canada's Gulf of St. Lawrence, lobsters are largely restricted to shallower waters that warm during the summer. Lobsters can be found in most nearshore waters off the northeastern United States, but the commercial fishery transitions from a predominantly nearshore one in Maine (within waters up to 300 feet deep) to a predominantly offshore fishery in the region's more southerly states (restricted mostly to the deep canyons at the edge of the continental shelf).

As cod are driven north by ocean warming, it is unclear whether this species will be able to find another location as well suited to its life cycle as Georges Bank.

Lobster landings in the United States have nearly tripled over the past 20 years, and a wide range of contributing factors has been proposed to explain the rapid increase. These factors include sharp increases in fishing activity and in the total area fished, enhancements in fishing technology, warming water temperatures (particularly in the Gulf of Maine), and harvest-driven declines in cod and other fish that prey on lobsters.[46] The recent rapid increase in water temperatures has lagged slightly behind the increase in lobster landings and therefore cannot be the sole explanation. Yet, a comparison of lobster distribution during the relatively cold period 1965 to 1969 with the warmer period 2000 to 2004 shows the center of lobster density has apparently shifted north.[47]

Although lobsters are generally described as living in bottom waters ranging from 41°F to 68°F,[48] the reality is more complex. The minimum and maximum temperature limits for lobster survival vary somewhat with the oxygen content and salinity of seawater.[49]

Effects of water temperature on lobster

As with most marine organisms, warmer temperatures increase lobsters' respiration rate and oxygen needs while reducing the amount of dissolved oxygen available (because oxygen solubility in water declines with increasing temperature). Recent research on lobsters in Long Island Sound confirmed that as the water temperature rose above 69°F, the animals' respiration rate increased to the point where their demand for oxygen exceeded the available supply, causing physiological stress.[50] As a result, the Connecticut Department of Environmental Protection uses 68°F as a physiological stress threshold for lobsters in these waters.

By mid-century, ocean warming is projected to eliminate suitable lobster habitat in Long Island Sound.

Other factors that affect lobsters' tolerance of temperature extremes include the temperatures to which they have become acclimated and the stage of the molt cycle. The lethal cold limit has been found to be 35°F for lobsters acclimated in a laboratory to 62°F water, but 41°F for lobsters acclimated to 81°F.[51] Molting occurs during the warmer months of the year, and molting lobsters are less resistant to high temperatures, low amounts of dissolved oxygen, and low salinity.

Temperature also affects lobsters' physiology and behavior throughout their life cycle. The annual hatch, for example, generally occurs first in the warmer, southern end of the lobster's range and later in the colder, northern parts.[52] Temperatures above 75°F are lethal to larval and postlarval lobsters; in turn, temperatures below 54°F severely inhibit their development.[53] Continued warming of bottom waters could make new nursery grounds available in northern areas that have historically been too cold for settlement of postlarval lobsters.

Another example is the impact water temperatures have on the growth rates of juvenile and adult lobsters. In waters colder than 41°F, lobster metabolism slows to the point where molting does not occur. In stressfully warm waters, lobsters may fail to molt or may even die in the process.[54] Within the acceptable temperature range, warmer waters such as those in the northern Mid-Atlantic Bight host some of the fastest-growing lobsters, while lobsters in colder parts of the range grow more slowly. Warmer temperatures not only cause lobsters to grow faster but also accelerate the onset of maturity, meaning the animals mature at a smaller size.[55,56]

Finally, temperature tolerances strongly affect the movements and seasonal migrations of lobsters.[57] As waters warm in the spring, for example, lobsters become more active and move into the warming shallows of bays and estuaries.

Since at least 1979, average August bottom temperatures in Long Island Sound have been rising and have exceeded the 68°F stress threshold more frequently. In the summer of 1999 lobsters in the sound began dying in alarming numbers; by 2003 lobster populations there had fallen to 70 percent of their 1998 levels. In New York during the same time frame, landings in pounds dropped 88 percent (falling 85 percent in value), and in Connecticut, landings fell

The Northeast Lobster Industry: Potential Gains and Losses

Maine lobster boats with lobster traps stacked on a pier in Portland, ME. Maine lands more than half of the annual U.S. lobster catch and depends on the shellfish as a key tourist attraction. As waters warm, areas south of Cape Cod are projected to lose their coastal lobster fisheries by mid-century, but Maine may see its lobster habitat expand.

82 percent (falling 73 percent in value).[58] The value of landings in these states dropped from $42 million in 1998 to $10 million by 2002, putting many lobstermen out of business.[59]

The stocks have yet to recover. Although a number of factors played a role in this die-off, warmer water temperatures seem to have set the stage. Bottom water temperatures in Long Island Sound that summer were at highs for the decade and, in some locations, exceeded 74°F in August. Temperatures above 70°F continued into October.[60] Lobster numbers at the time were near historic highs, and as the animals moved to deeper, cooler waters to escape the warm shallows, they became increasingly crowded and subject to oxygen stress and exposure to disease. Many of the weakened lobsters were afflicted with paramoebiasis, a potentially fatal condition caused by a parasite.[61] Although the dockside value of the lobster fishery in the southern part of the Northeast has historically been modest compared with states to the north (in 1998, prior to the Long Island Sound die-off, combined lobster landings in Connecticut, New Jersey, New York, and Rhode Island represented 23 percent of the Northeast total), the sharp decline in landings since 1999 has created hardships for local lobstermen and their communities.

Using the methods outlined above to generate projected bottom temperatures (Table 2), our analysis yielded the following trends in future lobster distribution:

The northern Mid-Atlantic Bight

- The maximum 68°F stress threshold for lobsters is projected to be consistently exceeded by mid-century in Long Island Sound and other near-shore areas of these waters, resulting in the likely loss of suitable habitat under both emissions scenarios.
- More frequent episodes of temperatures in the high-stress range (near 80°F) are also likely in the region's southern coastal waters.
- Deep waters and submarine canyons, which currently support significant lobster populations, are unlikely to be affected.

Georges Bank

- Lobsters in these waters are found at the highest densities in submarine canyons where they are unlikely to be exposed to stressfully warm water temperatures.

Lobstering: A Lucrative but Precarious Way of Life

The American lobster is one of the Northeast's most valuable commercial catches—Maine lobstermen alone hauled in more than 70 million pounds of lobster worth $311 million in 2005. The industry also supports many jobs across the region, with over 7,000 commercial harvesters in Maine alone in 2006. As waters warm and lobster ranges shift, lobstermen will need to adapt to the changes and manage the remaining stocks in a sustainable manner.

The Gulf of Maine

- In contrast to the southern part of the region, warming in these colder northern waters may actually boost lobster populations by spurring a longer growing season, more rapid growth, an earlier hatching season, more nursery grounds suitable for larval settlement, and faster planktonic development (which could increase survival and settlement).
- Some northern parts of the region where thermal conditions have probably limited larval lobster settlement in the past may become more hospitable during this century due to warming. This includes the coast of Maine east of the Schoodic Peninsula, which seldom has summer bottom water temperatures above 54°F (except in the upper portions of shallow bays and inlets). Lobster harvests per square mile of seabed along this coast have typically been lower than the central and western parts of Maine's coast.

Cape Cod Faces an Uncertain Future

Cape Cod is a dynamic landscape under increasing pressure from both humans and the sea. Retreating glaciers deposited this peninsula 14,000 years ago and left it to the mercy of the elements. Now, sea-level rise associated with global warming is intensifying the threat that sprawling development and a growing population pose to Cape Cod's idyllic character.

Since the building of the Mid-Cape Highway (U.S. 6) in the 1950s, forested land and other open space has been lost at an ever-increasing pace to houses, shops, tourist facilities, golf courses, and other developments, which now occupy nearly one-third of Cape Cod's land mass. The population doubled between 1950 and 1970 and has now doubled again, bringing today's year-round population to 230,000.[62]

From April into September, that population triples as tourists flock here to escape city heat, relax on pristine beaches, stroll or cycle through the woods, sail, whale-watch, fish in the bays and freshwater ponds, dine on locally harvested lobster and scallops, or catch ferries to nearby Martha's Vineyard and Nantucket Island. Cape Cod National Seashore preserves many of the area's iconic white sand beaches, dunes, grassy heaths, pine and oak woodlands, glacially carved wild cranberry bogs, cedar swamps, and salt marshes. This landscape also remains a birder's paradise, providing safe nesting habitat for endangered piping plovers, roseate terns, and other migrating shorebirds as well as playing host to thousands of waterfowl such as eiders, scoter, red-breasted mergansers, and brant during the fall and winter.[63]

Although tourism and construction now dominate the local economy, traditional ways of life such as fishing, lobstering, and farming still persist. Agriculture—from the bogs that launched the modern cranberry industry to small herb farms and pick-your-own-produce fields—remains an important but diminishing part of Cape Cod's character; its share of the peninsula has shrunk from 20 square miles in 1951 to only six square miles today.[64]

Historically, tourist crowds vanished in winter and many of the local shops and restaurants closed their doors for the season. But Cape Cod is increasingly becoming a year-round population center as more summer homes are converted into full-time residences and luxury home developments spring up in previously open space.[65] Development and population pressures, in turn, have generated ongoing concern about vehicle traffic, open space, wildlife habitat, the quality and supply of groundwater, nutrient pollution of coastal waters, and the overall quality of life.

Changes in sea level and shoreline

Even as human pressures mount, wind and waves have been steadily reshaping Cape Cod. The sea reclaimed three square miles of the shoreline between 1951 and 1990, and the peninsula has continued to lose an estimated 33 acres of land each year since then—about three-quarters of it to inundation by rising seas and the rest to active erosion by surf and storm waves.[66,67]

Nor'easters contribute most dramatically to the retreat and reshaping of the shoreline, especially along the ocean-exposed shore of the Outer Cape. The Blizzard of 1978, for example, cut Monomoy Island (a wildlife refuge at the "elbow" of Cape Cod) in two and swept away 40-foot-high dunes and houses from nearby Eastham. A 1987 storm similarly breached Nauset Beach near Chatham, opening an inlet that gradually widened to a one-mile gap by 2007, causing the loss of a number of newly wave-exposed homes. And when the "Perfect Storm" of 1991 broke through Ballston Beach in Truro, it temporarily turned the northern portion of the Outer Cape into an island.[68]

Global warming will exacerbate these effects. NECIA analysis projects that, with the sea-level rise expected under the higher-emissions scenario, Woods Hole could experience coastal flooding equivalent to today's 100-year flood every nine years toward the end of the century, and every 21 years under the lower-emissions scenario. (See the coastal impacts chapter.)

According to U.S. Geological Survey projections Cape Cod, Nantucket Island, and Martha's Vineyard are among the areas in the Northeast most at risk from accelerated sea-level rise.[69] During storms, their beaches may be subject to much greater erosion than would be caused by sea-level rise alone. These shorelines will also be more susceptible to breaching by storm waves. The prospect of greater storm damage combined with the escalating value of the properties at risk recently prompted major insurers to cancel thousands of homeowners' policies on Cape Cod. (See the text box on coastal insurance.)

Sea-level rise also creates the potential for saltwater intrusion into freshwater wetlands and Cape Cod's freshwater aquifer—especially when compounded by increased groundwater pumping to provide drinking water for a growing population.[70] (See the text box on water.)

Changes in marine life, birds and vegetation

Continued ocean warming may cause the cod that were once such an important part of the local economy to disappear from the waters off the south coast of Cape Cod during this century. These waters are also likely to lose their lobster fishery by mid-century.

Changes in air temperatures and the timing of seasons are already altering Cape Cod in other ways. Researchers analyzing 70 years' worth of data from the Cape Cod Christmas Bird Count have found changes in the composition of the winter bird community, as species with southern affinities such as the green heron, snowy egret, great egret, and red-shouldered hawk have become more common and birds with northern affinities such as the evening grosbeak, cedar waxwing, and great cormorant have become less common.[71] NECIA projections reflect these ongoing changes and suggest that far greater reductions can be expected in the abundance of a number of additional favorite bird species, particularly under the higher-emissions scenario. (See the forest chapter and the box on Northeast bird species.)

Warming temperatures also threaten Cape Cod's traditional cranberry crop. Though a small part of the state's overall cranberry industry today, Cape Cod is the original home of cranberry production. According to NECIA projections, by mid-century, cranberry production will be at risk in southeastern Massachusetts, especially under the higher-emissions scenario. (See the agriculture chapter.)

It is possible that warming waters could promote an increase in blue crabs in the southern part of the Northeast, and that some lobstermen could switch to this lucrative fishery. However, economic uncertainty is likely to continue for some time as global warming makes nearshore waters at the southern end of the lobster's range less hospitable.

As the Gulf of Maine warms, certain areas may become increasingly suitable habitat for lobster; they may also become more hospitable to "lobster-shell disease."

Farther up the coast, bottom temperatures can exceed 68°F in summer in the shallow nearshore waters of Boston Harbor and New Hampshire's Great Bay estuary. Though areas of Massachusetts Bay were not explicitly considered in this study, historic temperatures in these waters suggest that resident lobster populations may become increasingly vulnerable to thermal stress as waters warm over the course of the century. As the Gulf of Maine warms, certain areas may become increasingly suitable for lobster habitation; they may also, however, become more hospitable to certain diseases, such as the bacterial condition known as "lobster-shell disease," which is now observed only at low levels in these waters. (See the text box on marine ecosystems.)

CONCLUSION

The Northeast's coast from New York to Boston forms part of the most densely populated urban corridor in the nation, and the increasing demand from city dwellers for coastal land and recreational facilities adds to the pressures on the commercial fishing industry. Just as whale-watching tours have long since replaced the whaling fleets of Long Island and Nantucket, working docks where fishermen unload fish, lobster, and sea scallops are increasingly being replaced by recreational marinas and vacation-home developments in many historic fishing ports from Stonington, CT, to Stonington, ME.[72,73]

Climate changes already set in motion by recent heat-trapping emissions will intensify the uncertainty and stresses already affecting the Northeast's traditional fisheries. However, limiting further emissions to levels at or below the lower-emissions pathway used in this study would greatly reduce the consequences for the cod and lobster fisheries that have been synonymous with the region for centuries.

CHAPTER FOUR

Impacts on Forests

KEY FINDINGS

- **The character of the Northeast's forests may change dramatically over the coming century as the center of suitable habitat for most of the region's tree species shifts northward—as much as 500 miles by late-century under the higher-emissions scenario, and as much as 350 miles under the lower-emissions scenario.**
- **Many tree species, including the hardwoods that generate the region's brilliant fall foliage, may be able to persist this century even as their optimal climate zones shift northward. Other species, however, may succumb to climate stress, increased competition, and other pressures.**
- **If the higher-emissions scenario prevails, productivity of spruce/fir forests is expected to decline and suitable habitat will all but disappear from the Northeast by the end of the century. Major losses are projected even under the lower-emissions scenario. This would greatly exacerbate stresses on the pulp and paper industry in the Northeast, particularly in Maine, where the forest-based manufacturing industry is key to the state's economy.**
- **Diminished spruce/fir habitat, especially at higher elevations, would increase pressure on associated animal species such as the snowshoe hare, Canada lynx, and Bicknell's thrush, one of the region's prized songbirds. With the late-century summer warming projected under the higher-emissions scenario, suitable habitat for the Bicknell's thrush could be eliminated from the region.**
- **Substantial changes in bird life are expected across the Northeast due to rising temperatures, shifting distribution of suitable habitat, or declining habitat quality. The greatest changes are projected under the higher-emissions scenario, including declines in the abundance of many migratory songbirds such as the American goldfinch, song sparrow, and Baltimore oriole.**
- **Winter warming will threaten hemlock stands, not only by reducing suitable habitat for these trees, but also by allowing northward expansion of a fatal pest known as the hemlock woolly adelgid—as far north as Canada by late-century under the higher-emissions scenario.**

BACKGROUND

Extensive forests dominate much of the landscape of the Northeast, including nearly 90 percent of Maine and New Hampshire. They range from the maple, beech, and birch northern hardwood forests that dazzle residents and tourists alike with their red and yellow foliage displays each fall to the storied North Woods of Maine, where wild rivers flow through dense forests of spruce and fir. The number of forested acres across the Northeast increased throughout much of the past century as trees were allowed to reclaim land once cleared for farming. People across the region value their woodlands for timber and firewood, scenery and solitude, and a wide range of recreational opportunities such as hunting, fishing, skiing, snowmobiling, hiking, canoeing, and bird-watching. In the northern Northeast states (Maine, New Hampshire, New York, and Vermont) the annual economic contribution of the forest industry and forest-based tourism combined was estimated at $19.5 billion in 2005.[1]

The Northeast is the original location of much of the nation's wood-based industry. After a long period of stability in the second half of the last century, all branches of the industry are restructuring and some are shrinking.[2] Yet mills and forest-product plants, small and large, remain important to the economic base of many communities.[3] Forestry and related industries also provide more than 300,000 jobs in New England and New York alone, although global competition and mechanization are taking a toll. Maine, for example, lost nearly one-quarter of its loggers, mill workers, and other forest-industry jobs (more than 5,000) between 1997 and 2002.[4,5] At the same time, traditional forestry and paper companies have been selling off vast tracts of timberlands. Since the late 1990s, more than one-third of Maine's land, for example, has changed ownership.[6,7] About 6 million forested acres across the northern Northeast states have been sold in this same period.

As suitable habitat shifts, trees may become less productive and more vulnerable to competition.

Some of North America's most complex mixtures of tree species occur in the Northeast, where the more boreal forests to the north transition to the more temperate hardwood forests to the south.[8] Climate change is not expected to cause a net loss of forested land, but it is projected to alter the character of the region's forests over the coming century. Some current forest types would give way to new forest types that will have combinations of species different from those we know today.

The forest types that characterize various parts of the Northeast are defined by their major constituent tree species: for example, white/red/jack pine, oak/hickory, spruce/fir, or maple/birch/beech. Each species within these forests has unique habitat requirements. Climate plays a major role in determining suitable habitat for trees (i.e., where individual tree species can establish themselves, grow, and survive). It also has a significant effect on how quickly trees grow and how entire forest ecosystems function (in terms of how they cycle water and nutrients). In addition, the rising atmospheric CO_2 levels that drive global warming have the potential to affect trees and other plants directly, possibly spurring greater growth and more efficient water use while also increasing plant demands for soil nutrients.

As the climate of the region warms, the areas that best meet each tree species' requirements will shift, sometimes dramatically. The extent to which each species can persist or migrate to more suitable locations will depend on a combination of factors, including competition from other species, rates of seed dispersal (trees rely on animals, wind, or water to disperse their seeds), suitability of soils, the degree of stress caused by drought or warmer temperatures, and the existence of roads and human settlements.

The Northeast forests are also subject to numerous overlapping influences, ranging from invasive plants and overgrazing by deer to low-density sprawl and other changes in land use. Attempting to predict how such complex forests, affected by multiple forces, will respond to a changing climate is a challenging task. In addition, global warming may indirectly add to the pressures and uncertainties

A Treasured but Threatened Resource

Residents and tourists alike value the Northeast's forests (such as this mix of hardwoods and conifers in northern Vermont) for timber and firewood, scenery and solitude, and recreational activities such as hunting, fishing, skiing, snowmobiling, hiking, canoeing, and bird-watching.

facing the region's forests by changing the distribution of forest pests, pathogens, and invasive plant species, and potentially the frequency or intensity of ice storms, droughts, wildfires, and other major disturbances.

The eventual changes in forest composition and function could profoundly alter the scenery and character of the region, as well as the services the Northeast's forests provide. These services include recreation, tourism, wildlife habitat, timber and other forest products, protection of watersheds and drinking water supplies, carbon storage, nutrient cycling, and soil conservation.

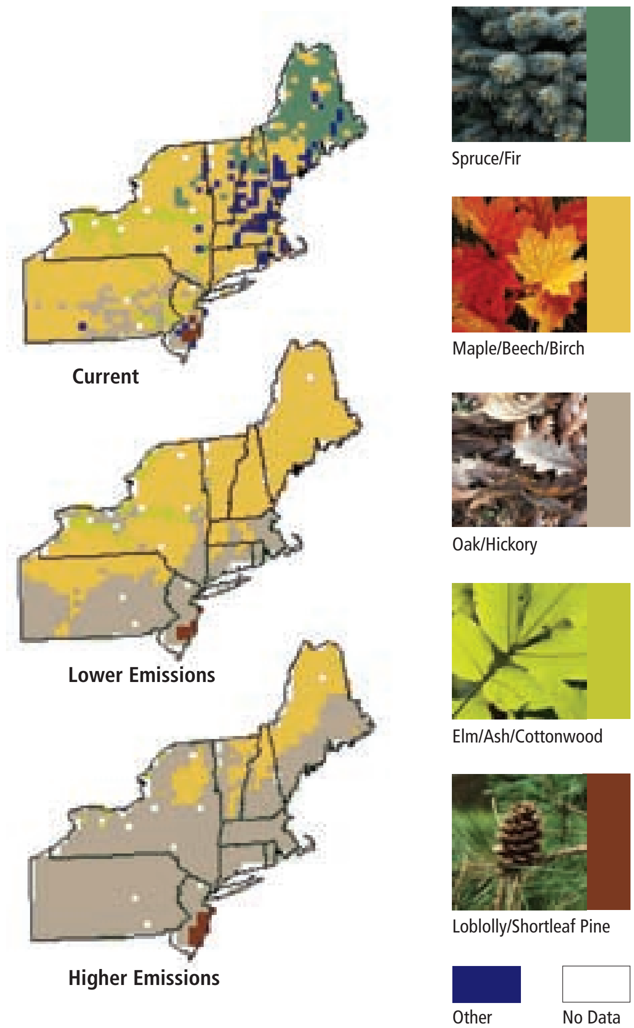
PROJECTED CHANGES IN NORTHEAST FORESTS

NECIA researchers modeled potential shifts in the distribution of habitat suitable for 134 tree species throughout the Northeast (based on their current climatic range) under both the lower- and higher-emissions scenarios.[9] Another NECIA analysis examined the potential impact of rising temperatures and atmospheric CO_2 (individually and combined) on productivity (growth), net carbon uptake, nitrogen cycling, and water yield in five forest research sites across the region.[10] A third analysis modeled changes in the expanding range of a forest insect pest, the hemlock woolly adelgid.[11] Finally, another study analyzed the way in which the distribution of birds might change as forest habitat shifts over time and habitat quality declines.[12]

Habitat suitable for most of the region's tree species is projected to move northeast as the climate continues to warm. The maximum range shift is projected to be about 500 miles in response to the climate changes expected this century under the higher-emissions scenario; the maximum range shift would be about 350 miles if lower emissions prevail. While trees can persist in areas where the climate is no longer well suited to their requirements, they may become less productive and more vulnerable to competition and other stresses, ultimately risking displacement by better-suited species.

Projections of forest productivity for the hardwoods that dominate much of the Northeast varied widely across the scenarios considered. Moderate to large increases in forest growth are projected if the warming associated with the lower-emissions scenario is combined with the "fertilizer" effect of CO_2 (whereby rising atmospheric CO_2 spurs increased forest productivity). Without CO_2 fertilization, projections ranged from small growth increases under the lower-emissions scenario to declines in growth by the century's end under the higher-emissions scenario. Projections for growth of spruce/fir forests showed a much greater sensitivity to climate

FIGURE 6: Changes in Habitat Suitability for Different Forest Types by Late-Century



Much of the Northeast is currently dominated by hardwood forests composed of maple, beech, and birch; higher altitudes and latitudes are dominated by spruce/fir forests. As the climate changes this century, suitable habitat for spruce and fir species is expected to contract dramatically under either emissions scenario (compared with observed forest distribution in the 1990s, shown here as "current"). Suitable maple/beech/birch habitat is projected with move significantly northward under the higher-emissions scenario, but shift far less under the lower-emissions scenario.[13,14] (The "other" category includes species such as red, white, and jack pine.)

Uncertainty for the Forest Products Sector

A decline in spruce/fir forests would greatly exacerbate existing stresses on the Northeast's economically important pulp and paper industry, particularly in Maine.

change, ranging from little change under the lower-emissions scenario to large growth declines under the higher-emissions scenario.

Tree species and the wildlife that depend on them will disperse across the landscape at variable and uncertain rates, some driven by the direct stress of climate change, some by competition from new species or attacks by pests migrating into the warming region, and others by human land-use decisions. Potentially major changes in bird life are likely across the Northeast even under the lower-emissions scenario, but the greatest changes would occur under the higher-emissions scenario.

It remains highly uncertain what the Northeast's forests will look like by the end of the century. Tree species will "migrate" across the landscape independently, not as ensembles or forest types. Instead of wholesale replacements of one distinct forest type with another, the Northeast can expect current forest ecosystems to slowly disassemble, leaving tree species to reassemble over time into new forest types that will have combinations of species different from those we know today.

Over the past 120,000 years of gradual climate shifts, there have been virtually no climate-driven extinctions of tree species in the Northeast because the native trees have been able to adapt from one end of the region's climatic range to the other.[15] However, the projected pace of human-driven global warming is too fast for most species to adapt, and some species with slower response times, narrow habitat requirements, or severely restricted dispersal may be unable to keep up as climate conditions change and their suitable habitat moves rapidly northward.

SPRUCE/FIR FORESTS

The most vulnerable of the Northeast's forests are the vast cool-climate communities dominated by conifers such as red spruce and balsam fir. These include forests such as the North Woods of Maine that are vital to the pulp and paper industry in the Northeast and equally treasured for their scenic and recreational value. In Maine, where the forest-based manufacturing industry is central to the state's economy, spruce and fir species provide 50 percent of all sawlogs and 20 percent of all pulpwood harvested.[16]

Suitable habitat for the group of species that make up spruce/fir forests is projected to diminish substantially with global warming under either emissions scenario. All areas of the Northeast now dominated by spruce/fir forests are projected to become less suitable for this group of tree species, and better suited to others. As this happens, habitat for different species of spruce and fir trees is projected to change at different rates, but these rates are consistently greater under the higher-emissions scenario.

- Under the higher-emissions scenario, balsam fir is projected to lose 70 to 85 percent of its suitable habitat across Maine, New Hampshire, New York, and Vermont, and red spruce is projected to lose 55 to 70 percent of its suitable habitat. For both species, losses will be greatest in Maine, where this forest type currently dominates the landscape.[17]
- Growth rates for spruce/fir forests are also projected to decline significantly throughout the latter half of this century under the higher-emissions scenario. The decline will begin earlier and be more pronounced if CO_2 fertilization does not occur.[18]
- Even under the lower-emissions scenario, suitable habitat for balsam fir is projected to decline 55 to 70 percent across Maine, New Hampshire, New York, and Vermont, and habitat for red spruce is projected to drop 45 to 65 percent. Again, the greatest losses are projected for Maine.[19]
- If lower emissions prevail, spruce/fir forests could experience some increase in growth rates as a result of more modest warming, a longer growing season, CO_2 fertilization, and more efficient water use caused by rising CO_2. Without CO_2 fertilization, however, forest productivity will likely decline even under lower emissions.[20,21]

The direct impact of rising atmospheric CO_2 on forest growth represents a major uncertainty in current projections of how future forests will function. Although experiments have shown that trees exposed to increased CO_2 exhibit accelerated rates of photosynthesis and growth over the short term, whether this will translate into sustained growth increases over longer timescales is unknown. There is also relatively little evidence for historical enhancements in growth in response to the 35 percent rise in CO_2 that has taken place since the onset of the Industrial Revolution.

Wildlife habitat

The spruce/fir forests of the Northeast are home to species such as the snowshoe hare, American marten, and endangered Canada lynx that are already living at the southern edge of their range. Thus, these species are vulnerable to any further loss of habitat in the U.S. portion of their range.[22]

High-elevation forest

High-elevation spruce/fir forests, confined to the Northeast's mountains, cover just 1 percent of the region's landscape today. These forests are currently restricted to specific climate conditions and are likely to see a decline in range as the climate changes. Only under the lower-emissions scenario is habitat suitable for these high-elevation forests likely to remain into the next century, though the long-lived nature of trees could enable patches of spruce/fir to persist for some time under either scenario. These forests, in turn, provide unique habitat for a number of threatened bird species. (See the text boxes on bird species and the Adirondacks.)

Industry

Dramatic declines in spruce/fir forests projected under the higher-emissions scenario would greatly exacerbate stresses on the Northeast's economically important pulp and paper industry, particularly in Maine. Winter warming, in addition to its direct role in redefining tree habitat, interferes with traditional timber harvesting practices in the region, which

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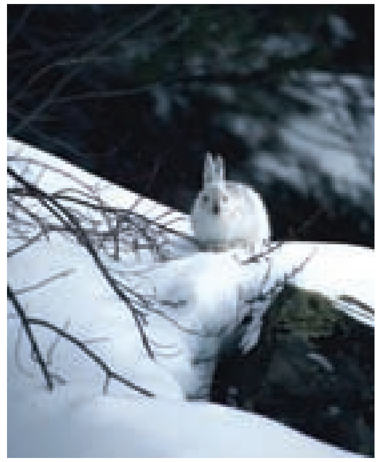
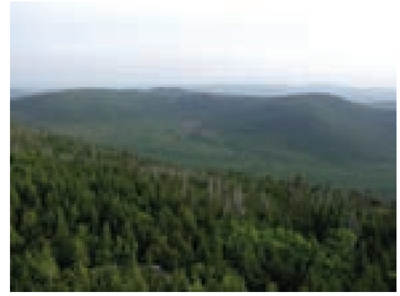




Species Pushed Northward

Declines in spruce/fir forests would pressure wildlife species, such as the snowshoe hare (above) and endangered Canada lynx (bottom). Under the lower-emissions scenario, pockets of suitable habitat for the Bicknell's thrush (at right) are expected to persist in the high elevations of New England, but under the higher-emissions scenario, this bird's distinctive song could eventually be muted as its suitable habitat gradually disappears.

Gains and Losses for Northeast Species

Dramatic changes in bird life are likely across the Northeast even under the lower-emissions scenario due to the shifting distribution of suitable forest habitat and declining habitat quality. The greatest and most rapid changes are expected under the higher-emissions scenario.[23]

Resident species. Bird species that call the Northeast home may fare well under both emissions scenarios in general, and many have the potential to increase in both range and incidence (an estimate of abundance) throughout the Northeast. These species include favorite visitors to the bird feeder such as the tufted titmouse and northern cardinal, as well as birds of prey such as the great horned owl and red-tailed hawk. Generalists like the blue jay, American crow, starling, house sparrow, and American robin show little change under either scenario.

However, the abundance of some resident birds may decline along with their preferred habitat, with somewhat greater losses under the higher-emissions scenario. These species include the ruffed grouse (Pennsylvania's state bird, which is prized by many hunters) and the black-capped chickadee (the state bird of both Maine and Massachusetts), though the latter's high tolerance for suburban habitat may curb its projected decline.

Migratory species. Bird species that migrate to the Northeast from neotropical and temperate climate zones actually make up the majority of birds breeding in the region. These species are likely to suffer losses in the amount and *quality* of habitat, and associated declines in abundance. For the American goldfinch, song sparrow, cedar waxwing, and Baltimore oriole, the decline in suitable habitat is significantly greater with higher emissions. For others, including the purple finch and hermit thrush (the state birds of New Hampshire and Vermont, respectively), the declines are significant under both scenarios.

Some species that currently occupy more southern areas of the United States, such as the blue grosbeak and hooded warbler, are projected to expand their ranges into the Northeast. Averaged across the region, net changes in total bird abundance may be small if southern species expand into areas where northern species are in decline.

High-elevation species. The most vulnerable species may be those that, like the Bicknell's thrush, depend on high-elevation spruce/fir habitat. Under either emissions scenario, great losses in suitable habitat are expected for this rare, mountain-breeding songbird as a result of climate changes projected this century. Only under the lower-emissions scenario is this range-restricted species projected to retain more than 10 percent of its U.S. habitat.[24,25] Mountain-breeding populations of spruce grouse, three-toed woodpecker, black-backed woodpecker, gray jay, yellow-bellied flycatcher, boreal chickadee, and blackpoll warbler are expected to be similarly affected.

- A summer temperature increase of roughly 4°F, projected by mid-century under either emissions scenario, may be enough to eliminate all breeding sites for the Bicknell's thrush at the southern edge of its range in the Catskill Mountains of New York and most of Vermont.
- With summer warming of 9°F, projected under the higher-emissions scenario by late this century, only small patches of suitable habitat for the Bicknell's thrush may remain in New Hampshire's Presidential Range and on Mount Katahdin in Maine.
- If summers warm by 11°F, also possible by late in the century under the higher-emissions scenario, suitable habitat for the Bicknell's thrush is expected to disappear from the Northeast.
- In the Berkshires of Massachusetts and the Allegheny Plateau in Pennsylvania, encroachment of hardwoods into mountaintop spruce/fir forests (projected as late-century warming reduces spruce/fir habitat) would threaten the remaining small populations of such species as the blackpoll warbler and yellow-bellied flycatcher. Further north, these species are less vulnerable because they occur in both high- and low-elevation spruce/fir forests.

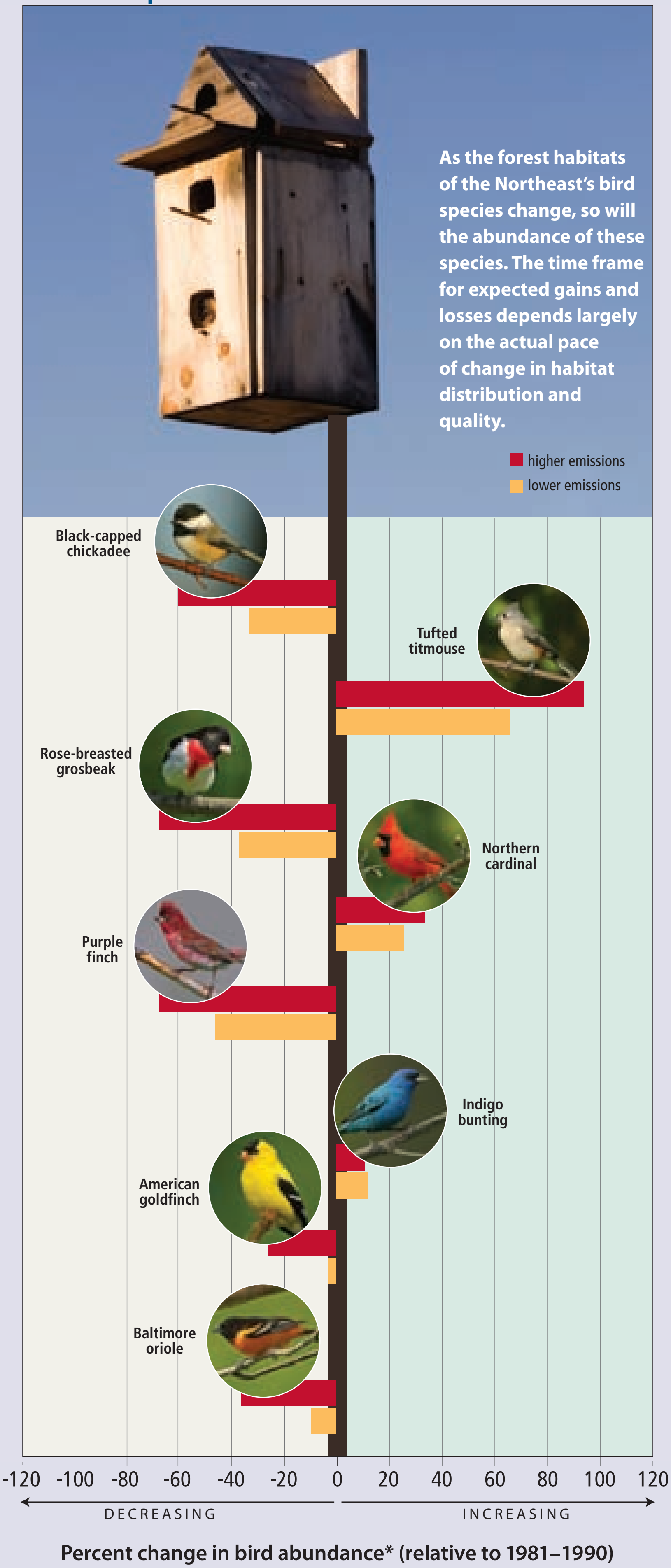
Wetland species. A number of wetland bird species such as the American bittern, common loon, and sora are projected to decline as a result of climate-driven changes including degradation of inland wetlands (due to summer drought and winter or spring flooding) and loss or degradation of coastal wetlands (due to rising sea levels).

Overall, significant change is projected for many of the Northeast's most colorful species, such as certain wood warblers; most beautiful singers, including the hermit thrush and veery; and iconic species, such as the Baltimore oriole, goldfinch, and common loon. Although many of the negatively affected species may persist in more northerly Canadian habitats, this will be cold comfort to bird enthusiasts in the U.S. Northeast.

Destinations of Some Migratory Birds Decline

Migratory songbirds like the black-throated blue warbler favor higher-elevation hardwood forest habitat, which provides an abundance of their favored food (caterpillars) and fewer nest predators, and leads to higher reproductive rates. Rising temperatures are expected to gradually reduce high-quality habitat for these birds.

FIGURE 7: **Potential Changes in Abundance of Bird Species**



* Abundance in this study represents how frequently a species is likely to be encountered within a given area (20 kilometers by 20 kilometers), based on 10 years of Breeding Bird Survey data. Percentage change in bird abundance is based on projected changes in suitable habitat by the end of the century.

typically take advantage of the cold winter months when soils are frozen, minimizing the soil damage that could be caused by the heavy equipment used for cutting trees. As winters continue to warm over the coming century, forest soils will remain frozen for shorter periods, freeze less deeply, or potentially not freeze at all in more southerly areas.

The industry may be able to cope by investing in timber harvesting equipment currently employed in other parts of the country where soils do not freeze. However, switching to new equipment can be expensive, and minimizing the economic impact will require that timber managers carefully weigh when climate changes are clear enough to warrant an immediate investment rather than waiting to upgrade as part of normal equipment turnover.

HEMLOCK STANDS

Eastern hemlock, another conifer species, is a long-lived, shade-tolerant tree that serves an important role in the mature forests of the Northeast. It often dominates stream banks in the southern parts of the region, providing dense shade that cools streams and creates favorable habitat for native brook trout. Hemlock faces a double threat from climate change: suitable habitat is projected to decline dramatically across the region by the end of the century, and warming will enhance the northward spread of the hemlock woolly adelgid, a non-native insect that has destroyed hemlock stands from Georgia to Connecticut.

- In New York, for example, the area of habitat that supports hemlocks is projected to shrink as much as 50 percent under the higher-emissions scenario, or half that under the lower-emissions scenario.[26]
- These trees may be able to persist in areas where the climate is no longer suited to them. However, winter warming projected under the higher-emissions scenario would allow the hemlock woolly adelgid to extend its range throughout Maine and into Canada, potentially eliminating hemlock from forests in the northeastern United States.
- If lower emissions prevail, however, cold winter temperatures may prevent adelgid infestations from moving north of central Maine.

Wildlife habitat

When hemlocks die, hardwoods such as birch often replace them and permit much more sunlight to penetrate the canopy, raising stream temperatures. Warmer water has a negative impact on stream-dwelling organisms such as native brook trout and the insects on which they feed. (See the text box on coldwater fish.) Several mammals and bird species are also closely associated with hemlock forests, including one of the Northeast's most colorful species, the Blackburnian warbler. Besides profound effects on wildlife, loss of hemlocks has been shown to alter soil characteristics, speed up decomposition and nutrient cycling, and degrade water quality by increasing nitrate runoff into streams.

A Spreading Threat to the Region's Forests

The hemlock woolly adelgid, an invasive insect from Asia that eventually kills the trees it infests, was first discovered in the Northeast in Pennsylvania during the 1960s. As of 2006, this insect had spread as far north as the southern counties of New Hampshire and Maine.

Pests and disease

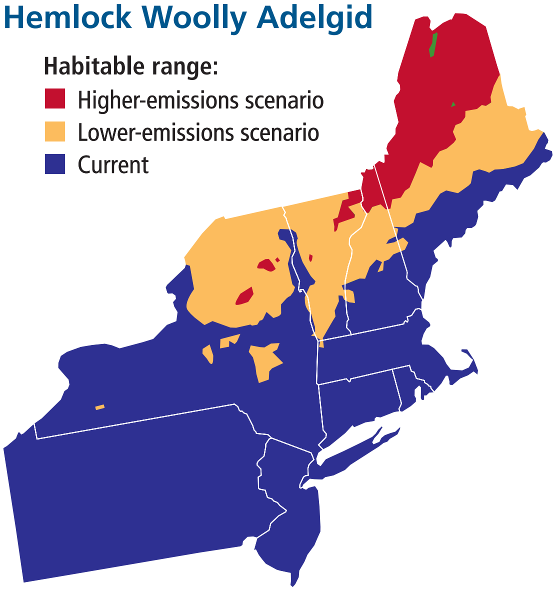
In recent years, many of the Northeast's communities have grown increasingly concerned about hemlock survival as the hemlock woolly adelgid has spread farther north. This aphid-like insect, introduced into North America from Japan in the early 1950s, feeds on a tree's sap, weakening and killing the tree within four to six years of infestation. Currently the adelgid can be found from northern Georgia to southern coastal Maine, with inland populations as far north as the southern borders of New Hampshire and Vermont. The insect has been slow to spread in Massachusetts, where some infested hemlocks have harbored adelgids for a decade or more without dying, presumably because severe winters limit the insects' abundance; the NECIA analysis finds that the hemlock woolly adelgid is likely to die after exposure to a mean winter temperature of 23°F.[27,28]

Other pests and pathogens that may benefit from global warming and accelerate the turnover of tree species in the Northeast's forests include the emerald ash borer, spruce budworm, pine bark beetle, gypsy moth, balsam woolly adelgid, Dutch elm disease, white pine blister rust, and beech bark disease. As climate change creates a habitat unsuited to the needs of mature trees, the resulting stress can increase the trees' vulnerability to pests and disease.

NORTHERN HARDWOOD FORESTS

From Pennsylvania into central Maine, much of the Northeast is dominated by hardwood trees, including the maple, beech, and birch responsible for the region's vibrant fall foliage.

FIGURE 8: **Late-Century Range of the Hemlock Woolly Adelgid**



Under the higher-emissions scenario, warmer winters could expose the entire region to the northward expansion of the hemlock woolly adelgid (normally kept in check by minimum winter temperatures) and the loss of hemlock trees. As of 2006, the adelgid was found as far north as southern New Hampshire, but could move farther north based on current temperatures.

- Northern hardwood forests may experience increased growth rates under either emissions scenario as a result of warmer temperatures, a longer growing season, and potential CO_2-driven increases in photosynthesis and water-use efficiency. If CO_2 fertilization does not occur, however, growth rates are projected to increase only modestly; under the higher-emissions scenario, they may begin to decline by the end of the century because of temperature stress.[29]
- Habitat suitable for many northern hardwood trees including maple, beech, and birch is projected to shift appreciably northward under the higher-emissions scenario, with comparatively small change under the lower-emissions scenario.
- Even under the higher-emissions scenario, maple, beech, and birch species may be able to persist for much of the century (particularly with increased forest productivity), until competition from incoming southern species causes their eventual replacement (with the likely exception of red maple; see below). However, these hardwoods could become more vulnerable to a number of threats under the higher-emissions scenario, including disease, pests, drought, wildfire, and severe storm damage.
- Under the higher-emissions scenario, oak-dominated forests such as oak/hickory and oak/pine are projected to eventually move into many areas now occupied by maple/beech/birch and other northeastern hardwood communities. Similarly, the northward shift in suitable habitat may cause species displaced from the northeastern United States to move into Canada.
- Suitable habitat is also projected to diminish for a number of other commercially valuable hardwood species, including black cherry, yellow birch, paper birch, quaking aspen, bigtooth aspen, American beech, and white ash. The changes would be much less extensive under the lower-emissions scenrio.[30]

Sugar maples

One of the most dominant and iconic tree species in the region, the sugar maple is projected to face dramatically declining habitat under the higher-emissions scenario; it would be spared from major contractions under the lower-emissions scenario.[31] And although this long-lived species may remain abundant even under the higher-emissions scenario, ongoing winter warming is expected to further

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Concerns over Native Coldwater Fish

In the centuries since European colonization of the Northeast began, native freshwater fish communities have lost habitat or suffered from habitat degradation caused by human activities such as logging, agriculture, and the stocking of many lakes and streams with non-native brown trout, rainbow trout, smallmouth bass, and other popular sport fish that prey on and compete with native species such as brook trout. Acid rain, suburban sprawl, and the "channelization" of streams have further reduced native populations in recent decades.[32] Now global warming adds a new threat to the survival of native coldwater species, as warmer conditions across the Northeast increase water temperatures, reduce winter snow and ice cover, and alter the timing, duration, and volume of seasonal stream flow.[33,34,35]

These species, including brook trout, lake trout, Atlantic salmon, and several types of whitefish, are described as "coldwater" fish because they generally require year-round access to water temperatures below 70°F. Summer temperatures in many northern streams and lakes have already risen beyond that threshold,[36] but native stream fish have continued to thrive due to the presence of small coldwater refuges such as tributaries and areas where groundwater enters a stream. Similarly, most northern lakes deeper than 30 feet "stratify" during the summer, a process that insulates water near the bottom from the warm air and provides a thermal refuge for lake fish.

Native Fish Require Cool Water

Hemlocks that are often found on the banks of the Northeast's streams provide the shade and cool conditions that native brook trout and other coldwater fish species need during the summer.

Coldwater refuges. As air temperatures continue to rise, average water temperatures in lakes and streams will also rise—a trend that may be exacerbated in streams by a decline in tree species such as hemlock that often provide shade for streams.[37] The impact on coldwater fish, therefore, will likely depend on the fate of refuges where they can survive the summers.

Larger streams where shade and thermal refuges are scarce are particularly likely to become less hospitable to brook trout, which are more sensitive to warmer water temperatures than non-native brown and rainbow trout.[38] Even under present-day conditions, brook trout are found further upstream than other fish species.[39] As conditions warm, brook trout may continue to be pushed upstream into small, cool tributaries.

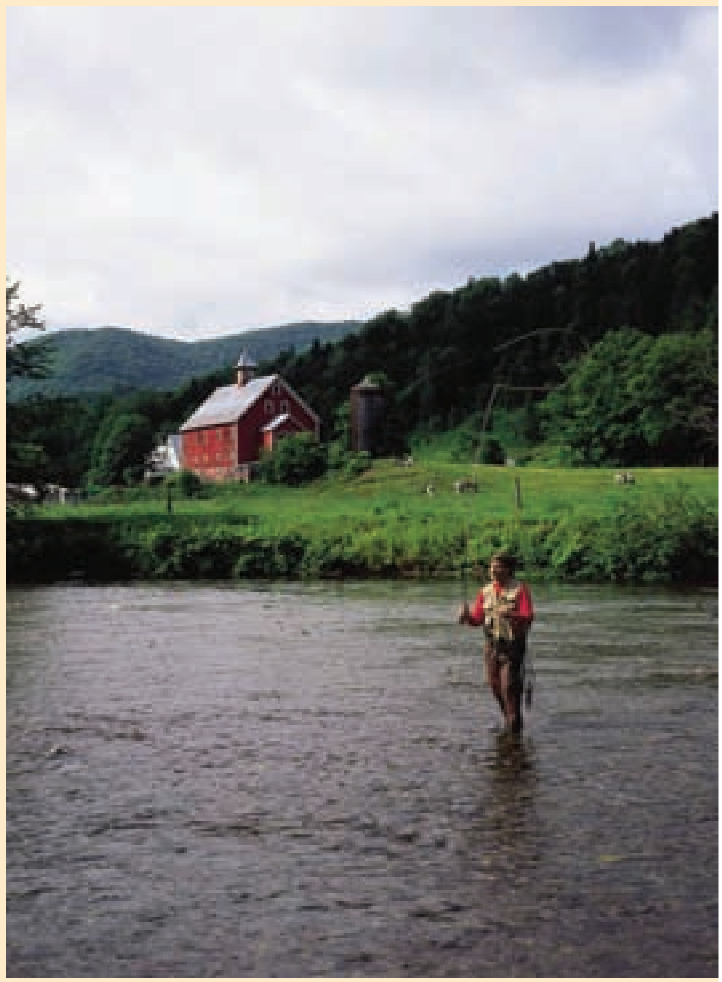
In many stratified lakes, fish are still likely to find coldwater refuges even as air temperatures warm.[40] But coldwater fish living in shallow lakes where such refuges are already limited will be more vulnerable to global warming. During several recent warm summers, for instance, brook trout populations in some shallow Adirondack lakes survived by taking refuge in small patches of cold groundwater entering the lake near its shore.[41,42] However, if climate change leads to reduced input of groundwater or increased groundwater temperatures, such refuges may disappear.[43,44]

Spawning and development. In the case of Atlantic salmon, which swim upstream from the ocean to spawn, increased summer warming has been projected to reduce smolt production.[45] Research also indicates that warmer freshwater temperatures may negatively affect the development of smolt and their capacity to survive in seawater.[46] Salmon fishing along Maine rivers such as the Penobscot once generated millions of tourist dollars each year, but dams, pollution, and other stressors have driven wild populations to near-extinction, forcing the state to close its rivers in an effort to save the fish.[47] Global warming threatens both Maine's restoration efforts and the Northeast's last stronghold for wild Atlantic salmon.[48]

Most native fish in the Northeast have adapted to seasonally changing water conditions. All major coldwater species, for example, spawn in late fall and spend the winter on the bottom of lakes and rivers, where they are usually insulated from severe cold and protected from storms by surface ice. The predictable onset and duration of ice cover are linked to the timing of egg hatching and larval feeding, which in turn determine the success of coldwater fish such as lake trout and lake whitefish.[49] Warmer winters with less consistent ice formation could threaten the survival of these species in northern lakes.

Predictable seasonal changes in stream flow also provide important cues for fish. For example, egg hatching is timed so that young fish can quickly seek refuge from the strong flow generated by spring snowmelt. Large changes in the timing of peak spring flow have already been measured in the last 50 years[50] and are projected to continue as winters warm, potentially disrupting this survival strategy. In addition, projected increases in winter rain could generate more damaging floods and ice flows that scour streambeds, killing eggs, larvae, and adult fish that cannot find suitable refuge.

Ironically, as average air temperatures rise, reducing the snow cover that insulates headwater streams, more coldwater fish may die from increased exposure to cold winter air. Reduced winter snow cover may also increase formation of streambed ice that can smother fish eggs and larvae while killing invertebrate prey living within the streambed, forcing fish to move to less suitable locations that are often occupied by predators or competitors.



Will Fewer Native Fish Be Biting?

Many residents of the Northeast, young and old, enjoy fishing on the region's quietly beautiful streams. Projected climate conditions, particularly under the higher-emissions scenario, would alter seasonal stream flow and diminish the shade along stream banks, threatening the survival of native coldwater species.

The Fall Spectacle of Northeast Hardwood Forests

Change for northern hardwood forests including the Green Mountain National Forest (pictured here) is likely under the higher-emissions scenario, but how quickly the current mix of maple, beech, and birch gives way to other forest types depends on factors such as competition from other species and damage from pests and wildfire.

disrupt the pattern of freezing nights and warm days needed for optimal syrup production. This means the trend of the past two decades, which has shifted the center of maple syrup production from the United States into Canada, is almost certain to continue.[51] (See the agriculture chapter and the text box on maple syrup.)

Red maples

This hardwood species is also projected to lose significant amounts of suitable habitat under the higher-emissions scenario, but could gain slightly if lower emissions prevail. However, the red maple has proven to be highly adaptive and has therefore become increasingly dominant over the past century.[52] Recent experiments, which showed that juvenile red maples experienced a growth boost of 130 percent when the soil in which they were grown was heated by 9°F,[53] suggest that red maples will likely continue to thrive as the climate warms.

ECOSYSTEM SERVICES

Global warming will alter not only the character of the Northeast's forests but also the services that forest ecosystems provide: timber, recreational opportunities, wildlife habitat, clean water, carbon storage, filtration and storage of pollutants, nutrient cycling, and soil conservation.[54] The exact nature of these changes will likely be complex and could include positive as well as harmful outcomes depending on the specific ecosystem service, actual emissions levels and the associated climate changes that occur, and the influence of non-climate-related factors.

- Overall forest productivity is likely to increase as atmospheric CO_2 concentrations rise and warmer temperatures lengthen the growing season. In turn, increased productivity should lead to a net increase in carbon storage in the Northeast's forests, but this could be offset by changes in human land use (such as timber harvesting or forest clearing for development) and the incidence of insect infestations, wildfires, storms, and other disturbances.
- Faster tree growth in the Northeast could create or expand opportunities to generate biomass energy using wood products.
- Although more productive forests will use more water over a longer growing season, this demand may be offset by a projected increase in rainfall combined with a CO_2-driven increase in water-use efficiency.
- Annual water runoff should show little change

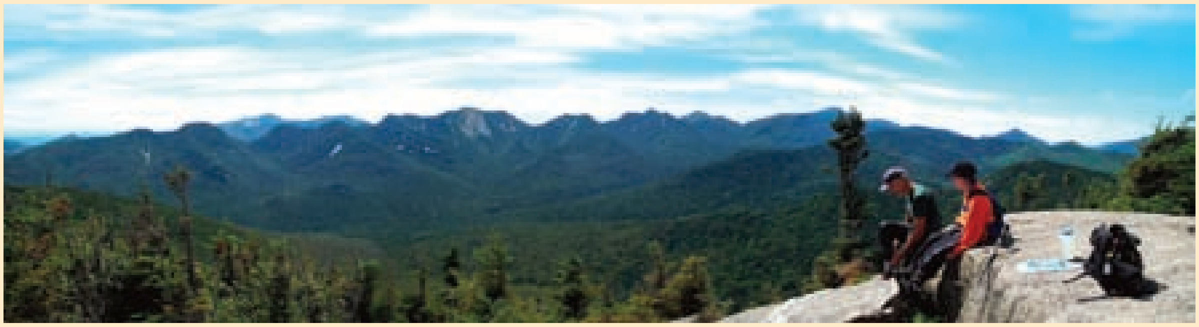
but, under either emissions scenario, periods of high stream flow in the spring are projected to occur earlier and grow shorter, while summer low-flow periods will last longer.[55,56,57,58] (See the text box on coldwater fish.)

- Shifts in forest types, faster decomposition spurred by warmer soils, and decreased winter snowpack could accelerate nitrogen losses from the Northeast's forests unless excess soil nitrogen is taken up to meet trees' increased nutrient demands.[59] Increases in the frequency of storms producing extreme precipitation may reduce water quality due to higher levels of nitrate and particulate runoff and turbidity.
- Invasive weeds such as kudzu and Canada thistle, which have both established footholds in the Northeast, have demonstrated a very strong growth response to rising CO_2 levels. (See the agriculture chapter.) As CO_2 increases, these species and weedy vines such as Japanese honeysuckle and black swallowwort can be expected to further invade Northeast forests.[60]
- Changes in the small but highly valued alpine tundra zones in the mountains of New England and New York, as well as projected declines in spruce/fir forests such as Maine's North Woods, may greatly alter the character of destinations prized by hikers and vacationers. (See the text box on the Adirondacks.)[61]
- The timing of fall frosts, which play a key role in determining the onset and vibrancy of fall foliage, is likely to shift later in the season, particularly under the higher-emissions scenario. The effect of this change on fall foliage is unknown, but if the region's colorful maple, beech, or birch species decline over the course of this century (a highly uncertain possibility), the tourism value of the Northeast's renowned fall foliage displays could suffer.

Uncertain Fate of High-Elevation Spruce and Fir

High-elevation spruce/fir forests and alpine areas—both at risk in a warmer Northeast—offer a prized destination for hikers, birders, and those in search of solitude.

The Adirondacks under Threat



Change on the Adirondacks' Horizon

Millions of tourists come to Adirondack State Park each year to enjoy its scenic vistas and recreational opportunities. The extent to which global warming will alter the landscape and its appeal as a destination is unclear, but its forests, alpine tundra, snowpack, birds, and fish are all at risk.

Today 7 to 10 million tourists[62] flock to New York's Adirondack State Park each year to admire the scenery, hike, swim, canoe, kayak, hunt, fish, ski, ice skate, and go snowshoeing or snowmobiling. *Audubon* magazine cites the park as one of the nation's top six destinations for bird-watching, and its 9,375 square miles are also home to otter, mink, beaver, black bear, moose, coyote, and pine marten.

More than 55 percent of the park's land remains privately owned, and 130,000 people live within its boundaries year-round; an additional 110,000 people live within the park on a seasonal basis.[63,64] Many permanent residents are employed by the tourism and retail sectors, and logging is important to both the local population and the state timber industry. Wood- and paper-product companies employ about 10,000 people in the region, which provides more than half of New York's softwood production and about 40 percent of its hardwood production.

This mosaic of land use and ownership has forced the park's managers to deal with the challenges of rampant subdivision and development along with environmental damage caused by acid rain[65] and mercury from coal-fired power plants.[66] Climate change will exacerbate both environmental and economic pressures on the park and may threaten the very survival of some of its most unique and rare ecosystems, particularly the spruce/fir forests and alpine tundra found in its most heavily used recreational areas.[67]

The Adirondacks contain the southernmost distribution of boreal forest or taiga in North America, a belt of conifer forests dominated by spruce and fir and laced with swamps and bogs that supports birds such as the gray jay, spruce grouse, black-backed woodpecker, boreal chickadee, Bicknell's thrush, and common loon. The bogs and fens of this boreal landscape harbor northern plants such as tamarack, black spruce, Labrador tea, bog laurel, dwarf cranberry, pitcher plants, and sphagnum moss.

A changing landscape. Under the higher-emissions scenario, suitable habitat for spruce/fir forests is projected to all but disappear from the Northeast by the end of the century. Even if lower emissions prevail, suitable habitat for spruce and fir could drop by half. (See the section on spruce/fir forests.) As a consequence, bird species that depend on this habitat are expected to decline in abundance. (See the text box on bird species.) Given the long life span of trees and the many uncertainties involved in projecting forest ecosystem changes, it is unclear what will replace these forests as they decline. The climate of the Adirondacks region is projected to remain suitable to the growth and survival of maple/beech/birch forests under either emissions scenario, even as surrounding areas become better suited to more southerly species.

Even more threatened than the forested landscape is the treeless alpine tundra. Of the park's

6-million-plus acres, only 85 currently support tundra habitat—and only half of that acreage is vegetated, supporting rare and fragile plants including dwarf willow, Boot's rattlesnake root, and purple crowberry, as well as mosses, lichens, and grass-like sedges.[68,69] These alpine habitats are found in the High Peaks wilderness region, the most heavily used (and protected) area of the park. Global warming is projected to further diminish—and perhaps even eliminate—this highly prized and already stressed ecosystem.

Anglers will also notice changes, as warmer winters with reduced ice and snow cover not only offer less protection for fish from harsh weather but also generate earlier spring stream flows that can harm trout. Rising summer temperatures may also deprive brook trout in Adirondack lakes of important coldwater refuges. (See the text box on coldwater fish.) Finally, the projected decline of hemlock trees that shade and cool mountain streams is also expected to diminish suitable habitat for trout and the aquatic insects on which they feed.

In winter, park visitors may be hiking more and skiing, snowshoeing, and snowmobiling less as warmer winters continue to reduce mountain snowpack, particularly under the higher-emissions scenario. (See the chapter on winter recreation.)

What the future Adirondack landscape will look like—its snow season, dominant trees, wildlife, forestry, agriculture, and recreational opportunities—cannot be projected with certainty. But change is certain and likely to be particularly pronounced under the higher-emissions scenario. For the local economies of the Adirondack region, where between 4 and 14 percent of the population is employed in the climate-sensitive forestry, fishing, and agriculture sectors, and where winter recreation is a lucrative attraction, this change could be deeply challenging.

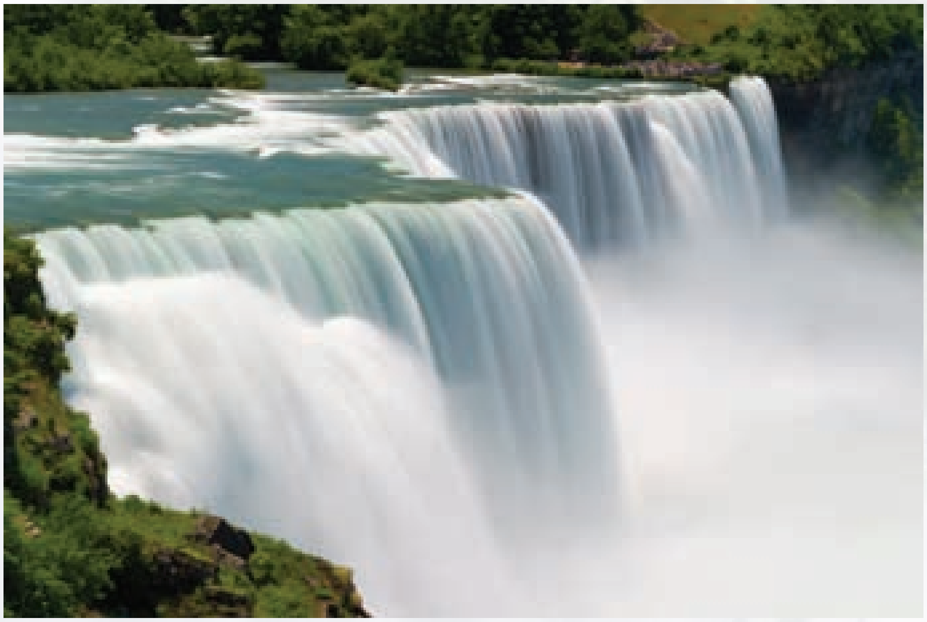
An Outdoor Haven

The Adirondacks are famous for outdoor recreation year-round. Mount Marcy, New York's highest point (reflected in this lake), is just one of the many prized destinations. Continued high emissions could threaten many popular winter activities in this region (twice the site of the Winter Olympics).

Water: A Vital Resource

A rich network of streams, rivers, lakes, and wetlands nourishes the Northeast's verdant landscape, creating an image of a region with abundant water resources. The Northeast is certainly water-rich in comparison with the western United States. Water supplies drawn from rivers, lakes, reservoirs, and underground aquifers quench the thirst of one of the most densely populated regions in the nation and also serve the needs of crops, livestock, industrial processes, and energy generation.

In addition, the Northeast's freshwater resources provide habitat for fish and other wildlife along with opportunities for recreational activities such as fishing and boating. In winter, frozen lakes and snow cover provide opportunities for skiing, snowmobiling, ice fishing, and other cold-weather pursuits. Each of these water uses may be affected by climate change.



A History of Abundant Water Resources

Images such as this view of Niagara Falls in New York reinforce the perception of the Northeast as a region rich in water resources. In the future, projected changes in the region's hydrology may require new approaches to water-resource management.

In the Northeast global warming is projected to affect water resources in the following ways.[1,2]

- **Alter the timing and amount of stream flow**, which would create:
  - more high-flow events in winter, particularly under the higher-emissions scenario, with an associated risk of winter flooding;
  - earlier peak flows in spring—roughly two weeks earlier under the higher-emissions scenario and 10 days earlier under the lower-emissions scenario; and
  - extended low-flow periods in summer—nearly a month longer by late-century under the higher-emissions scenario, with little change under the lower-emissions scenario.
- **Increase winter precipitation** (much of which is expected to fall as rain) 20 to 30 percent by late-century under either emissions scenario.
- **Reduce snowpack and shorten the snow season** in the typically snowy northern states—up to 50 percent by late-century under the higher-emissions scenario and more than 25 percent under the lower-emissions scenario.
- **Increase the frequency of short-term (one- to three-month) droughts**[3] by late-century from an average of once every two to three years to once every year across the Adirondacks, Catskills, and most of New England under the higher-emissions scenario, with little change under the lower-emissions scenario.
- **Increase the frequency of extremely hot days** (which can increase water demand) roughly five-fold under the higher-emissions scenario and two- to three-fold under the lower-emissions scenario.
- **Increase the likelihood and severity of damaging rainstorms** under both scenarios.
- **Raise sea levels** between 10 and 23 inches under the higher-emissions scenario and 7 and 14 inches under the lower-emissions scenario, increasing the risk of saltwater intrusion into coastal aquifers.

These projections raise a number of questions for Northeast water-resource managers—and users—including: will changes in hydrology lead to changes in water quality and supply? What impacts will these changes have on water demand, water-management needs, and broader resource-management concerns? To ensure adequate water supply and quality in the future, managers and users alike will need to take steps to better understand, minimize, and prepare for the emerging risks.

HOW CLIMATE CHANGE MAY AFFECT WATER RESOURCES

The increase in precipitation projected by the NECIA analysis could increase water supplies, especially in winter and spring, by increasing stream flow and runoff into lakes and reservoirs, and infiltration of surface water into aquifers. However, rising temperatures and changes in stream flow patterns could lead to decreases in water supplies during the summer and fall. Moreover, the timing of precipitation and the form it takes (i.e., snow or rain) strongly influence how much of the total precipitation is actually stored in surface waters and reaches aquifers. (See the climate chapter.)

For example, the projected increase in intense rainstorms could result in more soil saturation, which would lead to more runoff and hence diminished potential to replenish groundwater. Heavy rainfall also increases the risk of flooding that can contaminate waterways with sediment, sewage, pollutants, and pathogens.[4,5,6]

As winter snowpack declines, less water will be stored on the soil's surface as snow, which reduces peak stream flows when the snow melts in spring. Normally, when meltwater infiltrates slowly in spring and raises the subsurface water table, more water is discharged from seeps and springs, contributing to high spring stream flows and helping to maintain stream flows through the summer and fall. Diminished snowpack and earlier snowmelt may reduce the replenishment of groundwater, which can in turn reduce summer and fall stream flows. Studies in New England have already documented shifts in the timing of winter/spring and fall peak flows and associated measures such as last-frost dates, lake ice-out dates (i.e., when lake ice has completely thawed), and spring air temperatures.[7,8,9]

NECIA projections indicate that, under the higher-emissions scenario, short-term droughts could occur as frequently as once per year in the northern and eastern parts of the Northeast, while the frequency of medium-term and long-term droughts could also increase substantially in parts of upstate New York, placing new burdens on water-resource management systems.

Another factor affecting water supplies will be the changing demands of forests, crops, and other vegetation under higher temperatures and concentrations of CO_2 in the air. (See the forests chapter.) As global warming lengthens the growing season and spurs enhanced plant growth, water supplies could also decrease due to evapotranspiration (i.e., the loss of water from the surface of water bodies, the soil's surface, and the pores on plant surfaces).

Finally, rising sea levels and occasional storm surges will exacerbate the problem of saltwater intrusion into coastal freshwater aquifers and the mouths of rivers.[10]

As the Northeast's climate changes, a key concern of water-resource managers is whether more or less water will be available in the region's aquifers, rivers, lakes, and reservoirs, and how that supply may change over the course of the year. Although few quantitative projections of changes in regional water supply and quality are available, it is important to explore these concerns as well as the adequacy of infrastructure such as dams and reservoirs.

Water supply

Towns and cities traditionally draw most of their water supplies from surface-water systems—sometimes natural lakes and ponds, but more often storage reservoirs (as is the case for Boston and New York City). In the

Hot Summers, High Water Demand

Projected increases in summer temperatures, short-term drought, and extended low-flow conditions under the higher-emissions scenario could both increase water demand and tax water supplies.

past, droughts in the region have been relatively infrequent compared with the western United States. Thus the reservoirs for both small and large communities in the Northeast have less capacity to handle extended periods of below-average annual precipitation than their western counterparts.

Many of the region's public water systems are considered adequate to meet current and future water demands, but some are not. Brockton, MA, for example, is one of several towns in the region that have considered building desalination plants to supply additional fresh water.[11] There is also increasing pressure on larger water districts to supply smaller communities. Water managers throughout the region therefore need to evaluate the adequacy of their surface-water supplies and storage facilities in light of the projected increase in droughts.

In recent decades groundwater has become an increasingly important resource, now supplying about one-third of the water used in the Northeast—including more than half the public drinking water in Maine, New Hampshire, and Vermont.[12] The most productive and readily replenished groundwater sources are aquifers situated in sand and gravel such as those underlying Cape Cod, Long Island, parts of New Jersey, and numerous river valleys throughout the region. Although bedrock aquifers (which underlie most of the Northeast and are more slowly replenished) rarely serve as a large-scale water supply, millions of people—especially in rural areas—obtain their water from wells drilled into bedrock. Depending on local hydrological and geological conditions, these groundwater users may be highly vulnerable to extended drought.

Because the productivity of aquifers is closely connected to that of streams and rivers in many watersheds, pumping from wells can have an impact similar to drawing water directly from rivers. In some summers, for example, when stream flows are naturally at their lowest levels, overpumping of water from wells in Massachusetts' Ipswich River basin has caused nearly half of the 45-mile-long river to go dry.[13] In 2003 this trend, combined with high water demand from surrounding cities, landed the Ipswich River among the top three most endangered U.S. rivers according to the conversation group American Rivers.[14]

More than 330,000 people, both within and outside the Ipswich River basin, rely on its surface and groundwater supplies. Rapid growth of housing developments in the basin has led to growing concern about these supplies, especially in the face of projected increases in summer heat, drought, and low stream-flow conditions. As a result, the U.S. Geological Survey has invested significant resources in assessing stream-flow requirements for habitat protection, developing a precipitation/runoff model for the basin, and evaluating the effects of water-management alternatives on stream flow.[15] Water-resource managers can use these types of studies to better understand how the region's basins may respond to increasing drought combined with additional stressors such as population growth and changes in land use.

In several of the Northeast's coastal areas, including southeastern New England, Cape Cod, and southern New Jersey, excessive groundwater pumping exacerbated by rising sea levels has produced saltwater intrusion problems. For example, pumping in the Camden, NJ, area has reduced groundwater levels enough to cause water from the adjacent Delaware River to flow into the aquifer.[16] During the extended drought of the 1960s, reduced flows in the Delaware River allowed saltwater to intrude further upstream and led to a dramatic increase in the amount of salt in Camden's wells.

New Jersey's Cape May peninsula has also experienced declining groundwater levels over many decades and a subsequent intrusion of saltwater that has forced water suppliers to move their wells inland.[17] The city of Cape May built a desalination plant to process the brackish groundwater before supplying it to residents. Given the rates of sea-level rise projected over the coming century—10 to 23 inches under the higher-emissions scenario and 7 to 14 inches under the lower-emissions scenario—water managers can expect saltwater intrusion prob-

Communities and Wildlife Depend on Adequate Stream Flow

Conditions of low stream flow are projected to last roughly a month longer by late-century under the higher-emissions scenario, with little change under the lower-emissions scenario. For communities dependent on streams and rivers for their water supply, this trend is cause for concern.

lems to intensify. Such projections will likely be revised upward when estimates of future polar ice melt are adequately incorporated in climate models. (See the climate chapter.)

The Northeast has not devoted as much effort as the arid West to reducing water demand from consumers and industries (including electric utilities). As a result the region still has an opportunity to reduce the average amount of water used per person or industrial process as its population continues to grow or changes in water supply occur. For example the Massachusetts Water Resources Authority (MWRA), which supplies water to 2.2 million Boston-area residents, has lowered water usage mainly by repairing and upgrading infrastructure. As part of this effort more than 350,000 homes were retrofitted with low-flow plumbing devices, and annual demand dropped from a peak of 336 million gallons a day (mgd) in 1987 to 225 mgd in 2005.[18]

Beyond the implementation of stricter state plumbing codes for new construction, campaigns to promote the retrofitting of existing homes with low-flow appliances and plumbing have generally been less extensive in the Northeast than those in the West (with notable exceptions at, e.g., a number of the region's colleges and universities). More widespread retrofitting combined with pipeline replacement and other upgrades, such as those implemented by the MWRA, thus have the potential to significantly reduce water use throughout the region.

Water quality, flooding, and droughts

The projected increase in extreme weather is likely to produce more flash flooding, threatening lives, property, and water-supply infrastructure such as dams. Increased flooding is also likely to exacerbate erosion, turbidity, and water-quality problems. While more flooding can be expected in

River Flooding Affects Water Quality

Heavy rainfall in 2004 turned the waters of the Susquehanna in Pennsylvania into a torrent, damaging many properties and negatively affecting water quality. Under either emissions scenario, extreme precipitation is projected to increase, potentially creating more frequent river flooding.

winter and spring, heavy downpours in summer may also cause short-term flooding events, interrupting longer dry periods, and even drought conditions. All of these events will affect future water quality in the region.

The Northeast has numerous small dams, both privately and publicly owned; many were built between the late 1800s and mid-1900s.[19] Even under the current climate conditions, changes in sedimentation and land use (e.g., sprawling residential and commercial development that aggravates runoff and flooding) have increased concerns that these dams could fail during extreme storms. Global warming, with its projected increase in severe rainstorms and flooding, could intensify that threat.

In addition, increased flooding is expected to worsen a number of water-quality problems. New York City's water managers, for example, already treat their reservoirs with alum to reduce the turbidity caused by flash floods. Furthermore, outbreaks of waterborne diseases caused by pathogens such as *Giardia* and *Cryptosporidium* have often been linked with heavy rainfall, surface runoff, and flooding,[20,21] which increase the risk that water supplies could be contaminated by sewage and decrease the effectiveness of water treatment systems.

Many communities in the Northeast are currently implementing combined sewer overflow (CSO) abatement programs to eliminate or significantly reduce the release of untreated sewage and storm runoff into streams following heavy rains. Overflows result when the amount of runoff exceeds the total capacity of sewers and/or sewage treatment facilities. Shifts in the magnitude and timing of storms could worsen existing sewage contamination problems and further burden communities already struggling with current climate conditions. In coastal areas such as New York City, the projected rise in the height of storm surges could also exacerbate sewer system backups and overflows. (See the coastal and Meeting the Climate Challenge chapters.)

CONCLUSION

The Northeast's rivers, streams, and lakes also support fish and other wildlife, and the health of these aquatic ecosystems is dependent on an adequate level of both stream flow and water quality. (See the text box on coldwater fish.) Healthy waterways are highly valued by residents and visitors not only for their aesthetic qualities but also for the recreational activities such as fishing, canoeing, and swimming they provide. As temperatures rise and precipitation patterns shift, confidence in the adequacy and quality of the Northeast's water resources will need to give way to management strategies that are informed by and responsive to the regions' changing climate.

CHAPTER FIVE

Impacts on Agriculture

KEY FINDINGS

- **Farmers in the Northeast will face increasing uncertainty and risk as they attempt to adapt to the effects of climate change.**
- **A longer growing season may allow farmers to experiment with new crops, but many traditional farm operations in the region will become unsustainable without adaptation strategies that could be quite costly in some cases.**
- **Without adaptation measures, increasing summer heat stress is projected, by mid-century, to depress milk production and the yields of a number of economically important crops across southern parts of the region, particularly under the higher-emissions scenario. By late-century under this scenario, milk production across much of the region could decline 5 to 20 percent in certain months, with the greatest losses in Pennsylvania and New Jersey. By contrast, little change is expected under the lower-emissions scenario.**
- **Parts of the Northeast are projected to become unsuitable for growing certain popular varieties of apples, blueberries, and cranberries by mid-century, since they require long winter-chill periods to produce fruit.**
- **European wine grapes are expected to benefit from warmer winters, but yields of native grape varieties such as the Concord are projected to decline.**
- **Weed problems and pest-related damage are likely to escalate, increasing pressures on farmers to use more herbicides and pesticides.**
- **An increasing number of storms producing heavy rainfall may delay spring planting and damage crops and soils, while more frequent droughts during the growing season—particularly under the higher-emissions scenario—could make irrigation essential for most high-value crops.**
- **By late-century many of these trends are projected to be highly pronounced across most of the Northeast under the higher-emissions scenario, but more constrained in magnitude and geographic extent under the lower-emissions scenario.**

BACKGROUND

From the cornfields and dairy barns of Pennsylvania and New York to the maple sugar shacks of Vermont and blueberry barrens of Maine, the Northeast produces more than $7.5 billion worth of agricultural commodities each year.[1] That output includes a significant share of the nation's dairy products, maple syrup, and high-value horticultural crops such as apples, grapes, and sweet corn. New York, for example, in addition to its role as a global financial and cultural leader usually ranks among the top three states for production of apples, grapes, fresh-market sweet corn, snap beans, cabbage, milk, cottage cheese, and a number of other commodities. In 2006 New York's vegetable production ranked fifth in the nation and was valued at $376 million.[2]

Across the region, family farms remain vital to the rural economy, helping to meet the growing demand for fresh, high-quality local produce, while preserving the open space valued by residents and

Northeast Farmers Face Increasing Uncertainty and Risk

The richness and scenic beauty of the Northeast's agricultural countryside, from this Pennsylvania cornfield to the blueberry barrens of Maine, define the region's character as distinctly as its urban skylines. As temperatures rise and precipitation patterns change, however, farmers will face increasing uncertainty and risk.

tourists alike. Economic viability has historically been and continues to be a major concern for these small farms, as well as for large commercial operations. Commodity prices for agricultural products in the Northeast and nationwide have fallen by two-thirds on average over the past 50 years while agricultural productivity has improved only 1 percent per year, which forces the agricultural industry to continuously focus on improving productivity and decreasing production costs.

Many traditional farm operations that currently drive the region's agricultural economy (particularly dairy operations) may become unsustainable without strategic and in some cases costly adaptations.

The IPCC's most recent assessment concluded that "moderate climate change" will likely increase yields of North American commodity crops such as corn, rice, soybeans, and wheat by 5 to 20 percent over the next few decades.[3] The Northeast's agricultural economy, however, is dominated by dairy and high-value horticultural crops. NECIA analyses show that over the course of this century rising temperatures and erratic weather conditions generated by global warming will threaten the productivity and economic viability of some crops and livestock that have been important to the region historically but are adapted to cooler temperatures.

The types of crops and livestock that do well in the Northeast will change as global warming intensifies. Warmer temperatures, a longer growing season, and the potential "fertilizer" effect of rising atmospheric CO_2 (which increases crop productivity) will markedly affect the region's agriculture, and could create opportunities for farmers with enough capital to take risks on new crops, varieties, or farm equipment and technologies better suited to the changing conditions.

The NECIA analyses used climate projections to evaluate the timing and frequency of events known to affect (positively or negatively) crops and livestock important to the Northeast's current economy. The assessment indicates that many crop yields are projected to decline because of increasingly frequent extreme heat and summer drought, inadequate winter-chill periods (required by some plants for optimum production of fruit), and increased pressure from weeds, pests, and/or disease. Under the higher-emissions scenario these effects are projected to occur sooner—in many cases by mid-century—and affect a larger geographic area of the Northeast than under the lower-emissions scenario.[4]

Many traditional farm operations that currently drive the region's agricultural economy (particularly

TABLE 3: Top Agricultural Commodities of the Northeast

State	Dairy	Hay	Grains	Vegetables	Fruit	Nursery
Maine	88	15	8	126	34	37
New Hampshire	51	8	1	9	9	53
Connecticut	57	7	1	19	15	246
New Jersey	29	12	30	168	87	366
New York	1,556	108	156	323	179	334
Pennsylvania	1,394	103	203	126	109	733
Rhode Island	4	1	0	6	2	38
Vermont	342	24	3	10	9	23
Massachusetts	57	11	1	38	56	154

Economic value (in millions of dollars) based on 2002 U.S. Department of Agriculture data.[5] Total value of the commodities listed here exceeded $7.5 billion.[6]

dairy operations) may become unsustainable without strategic and in some cases costly adaptations. These adaptations could range from new planting dates, varieties, or crops to improved drainage systems, irrigation capacity, or cooling capacity of livestock facilities.

DAIRY

With annual production worth $3.6 billion, the Northeast's dairy industry is by far the region's most economically important agricultural sector, and more than 80 percent of that production comes from New York and Pennsylvania. Global warming will negatively affect dairy and other livestock operations by increasing the intensity and frequency of summer heat stress, which can depress both milk production and birthing rates in dairy cows for weeks or even months. The optimal temperature for milk production ranges from 40°F to 75°F, depending on the humidity; for example, heat stress can occur at temperatures as low as 75°F when the relative humidity is 65 percent or higher, but at temperatures of 80°F, heat stress requires relative humidity of only 30 percent.[7]

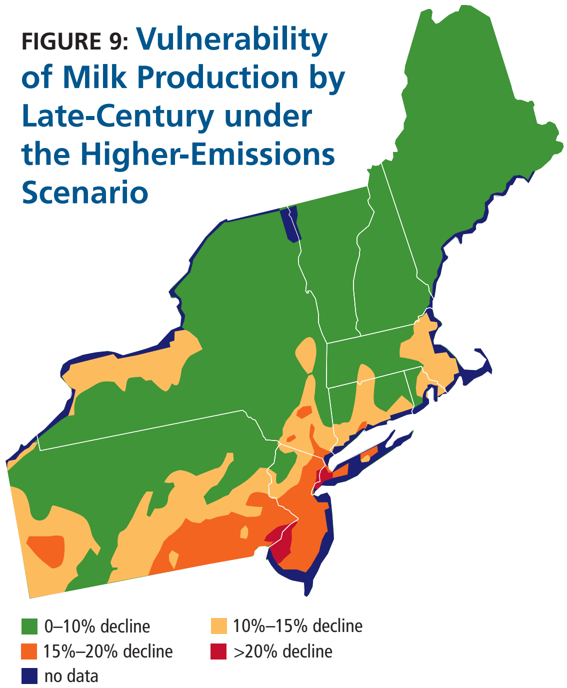
Heat stress already causes an estimated $2.4 billion in annual losses to U.S. livestock industries.[8] Within the Northeast, despite the region's historically moderate summers, losses have been estimated at $50.8 million per year for Pennsylvania, $24.9 million for New York, and $5.4 million for Vermont—the vast majority of which occurred in the dairy industry.[9] Rising summer heat threatens to increase these losses. In the unusually hot summer of 2005, for example, many New York dairy herds reported declines in milk production of 5 to 15 pounds per cow per day (an 8 to 20 percent decrease).[10]

Scientists have developed and validated a simple equation for determining the temperature and humidity threshold at which livestock begin to suffer heat stress. Called thermal heat index (THI), this

Higher Temperatures Depress Milk Production

Dairy cows are sprayed with water to keep them cool. The dairy industry is the most important agricultural sector in the region, with annual production worth $3.6 billion. Heat stress in dairy cows can depress both milk production and birthing rates for periods of weeks to months, driving down profits for an industry with an already small profit margin.

FIGURE 9: Vulnerability of Milk Production by Late-Century under the Higher-Emissions Scenario



This map shows the degrees by which July milk production is projected to decline by late-century (2070–2099) under the higher-emissions scenario. In the absence of investment in additional cooling capacity, much of Pennsylvania, for example, is projected to experience average losses in milk production of 10 to 20 percent for the month of July; losses of at least 5 percent are expected to be common across the region.[11] Under the lower-emissions scenario (not depicted here) the maximum projected decline is roughly 10 percent.

equation gives threshold THI values for heat stress of approximately 72 for dairy cattle, 72 to 75 for beef cattle, 72 to 74 for swine, and 70 to 78 for poultry. A NECIA analysis used climate models to evaluate average monthly THI values in the recent past and forecast regional changes in THI values for summer months under both emissions scenarios. The resulting values were then used to calculate changes in milk production.

- For the next several decades most of the region is expected to maintain an average THI for July below 72 under either scenario (meaning little increase in heat stress in dairy cattle and no significant heat-related reductions in milk production).
- By mid-century New Jersey and southern Pennsylvania are projected to experience moderate heat stress in July under the higher-emissions scenario: average THI values of up to 76, corresponding to declines in milk production of up to 12 percent. Under the lower-emissions scenario this decline is not expected until late in the century.
- By late-century all but the northern parts of Maine, New Hampshire, New York, and Vermont could suffer a decline in July milk production under the higher-emissions scenario. In parts of Connecticut, Massachusetts, New Jersey, New York, and Pennsylvania a 10 to 20 percent or greater decline in milk production is projected. Under the lower-emissions scenario, however, reductions in milk production of up to 10 percent remain confined primarily to New Jersey and small areas of Pennsylvania. It is important to note that the NECIA dairy analysis used average monthly temperature and humidity data that do not capture daily variations in heat stress and projected increases in extreme heat. These projections may therefore underestimate the impact of climate change on the industry.

Management techniques to reduce heat stress exist but could render all but the largest dairy operations unprofitable (especially if higher emissions prevail, which would demand more costly adaptation measures). The lowest-cost measures involve management and operational changes such as reducing overcrowded conditions, maximizing the available shade, and minimizing the time animals spend in hot holding areas. Farmers can also feed animals during cooler parts of the day, adjust the proportion of fats, proteins, and nutrients in feed, and increase the availability of drinking water. Dairy cattle, for instance, may need to drink 20 to 50 percent more water on hot, humid days.

Moderate-cost measures include improving insulation, ventilation, and fan systems in barns or installing misters or sprinklers to help with cooling. At higher cost, dairy operators with access to sufficient capital can design and construct new buildings and install air-conditioning systems in barns. Some of these costs might be offset by the effect warmer winters would have in reducing heating requirements.

Observers already consider the dairy industry "fragile," with little cash reserves to deal with unforeseen challenges (in part because overall U.S. milk and dairy consumption declined considerably in the second half of the twentieth century).[12] A complex pricing and taxation structure and considerable government control of milk prices do not allow the industry to respond flexibly to market fluctuations—although regulations and subsidies could be adjusted to help farmers adapt to the changing climate. Without such help, farms that are already struggling to remain profitable may not be able to afford the higher costs involved in adapting to a changing climate.

On the other hand, larger farms that can improve their cooling capacity may well benefit from climate change, especially if dairy operators in the warmer southern parts of the region or the nation go out of business.[13] This could result in a general northward shift of dairy production, with large corporate enterprises in the Northeast gaining market share.[14]

CROP PRODUCTIVITY

The future productivity of both crops and natural vegetation in a changing climate depends on a complex interplay of temperature and rainfall averages, daily and seasonal extremes in weather, changing atmospheric CO_2 concentrations, and competition from weeds, pests, and invasive species. Some plants will do better than others, and the recent warming trend in the Northeast provides clues to those that are likely to benefit and those likely to be disadvantaged among the region's important crops.

Temperature

Spring is arriving earlier in the Northeast, as shown by the advance in first-flower or first-bloom dates for a number of plants in the region including lilacs and grapes.[15] The length of the frost-free growing season across the Northeast has increased by 2.4 days per decade since 1970 and currently lasts about half the year (185 days); NECIA climate projections indicate the growing season may be another two to four weeks longer by mid-century. By the end of the century, the growing season is projected to lengthen an additional four weeks under the lower-emissions scenario and six weeks under the higher-emissions scenario.[16]

The warming now under way may already be having both positive and negative effects on crop productivity in the region. Indeed, the rapid expansion and success of the European wine-grape industry in upstate New York during the past 20 years can be attributed, at least in part, to less severe winters and reduced risk of vine and root damage.[17] In contrast, western New York has suffered lower apple yields in years when winters were warmer than average, possibly because warmer winters lead to poorer fruit set.[18]

An extended frost-free period will tend to benefit those farmers attempting to grow crops that require a long growing season (which are currently marginal or risky in the Northeast), such as watermelons, tomatoes, peppers, peaches, and European red wine-grape varieties. However, all crops in the region will face increasing summer heat stress, drought, and pressure from weeds and pests.

By the end of the century, the growing season is projected to lengthen an additional four weeks under the lower-emissions scenario.

Many important grain crops such as field corn, wheat, and oats tend to have lower yields when summer temperatures rise. Heat accelerates the plants' developmental cycles and reduces the length of time during which the grains' kernels need to mature.

In many other plant species, increases in the frequency of hot daytime or nighttime temperatures during spring and summer (a threshold of 80°F to 95°F, depending on the species) can negatively affect flowering, fruit set, seed production, or fruit quality. For example, common snap beans are sensitive

A Longer Growing Season Comes with a Price

An extended growing season will tend to benefit those farmers attempting to grow high-value crops that require long, warm summers, such as watermelons, tomatoes, peaches, and certain wine grapes. However, as the region warms, all crops will face increasing summer heat stress, drought, and pressure from weeds and pests.

to nighttime temperatures above 81°F, and tomatoes—although they are generally considered a crop adapted to warm seasons—can suffer reduced yields or fruit quality when daytime temperatures exceed 90°F for short periods during critical stages. Summer heat stress is particularly detrimental to some crops adapted to cooler temperatures, such as the cabbage, potatoes, and apples that currently dominate the farm economy in parts of the Northeast. While varieties adapted to warmer temperatures or other stresses such as drought may be available in some cases, the local market may not accept the new varieties, or the harvest window of these varieties may not be optimal in terms of market prices and competition from other regions.

While specific temperature thresholds for heat stress may vary slightly with species or timing, NECIA climate projections of increases in the number of summer days exceeding 90°F provide a useful indicator of how heat stress could affect future crop yields and quality. Currently the number of such potentially damaging days in July ranges from about 5 to 10 days in southern parts of the region to zero to five in the more northern parts.

- Farmers in the southern half of the region (much of Connecticut, New Jersey, Pennsylvania, and southern New York) could see 5 to 10 additional July days of heat stress within the next several decades (for a total of 10 to 20 such days). In northern parts of the region less than a five-day increase is projected.
- By late-century under the higher-emissions scenario, most July days are projected to exceed 90°F in the southern part of the region. Northern parts of the region are projected to experience 10 or more additional July days over 90°F—roughly half of the month in heat-stress conditions.
- By late-century under the lower-emissions scenario, southern parts of the region can expect roughly 8 to 12 additional heat-stress days in July (for a total of two to three weeks), while more northern areas can expect 5 to 10 such days (for a total of one to two weeks).

Warmer winter temperatures will also have a profound effect on the region's plant life and agricultural crops, particularly for the many varieties that require a prolonged period of winter chill and dormancy for optimum flowering, fruit set, and seed development. Important examples include apples, blueberries, grapes, and cranberries, as well as winter wheat.

Chilling requirements (often approximated by calculating the cumulative hours below roughly 45°F) vary considerably between species and even among varieties of a single species. For example, the requirements for common apple varieties such as Gala, Fuji, Red Delicious, McIntosh, and Empire fall between 400 and 1,800 cumulative hours.[19] Both

Traditional Fruit Crops May Suffer in a Warmer Climate

Many apple varieties, and a number of other fruits, require roughly 1,000 hours below 45°F each winter in order to produce good fruit yields the following summer and fall. By late this century under the higher-emissions scenario, winter temperatures are projected to be too warm across much of the Northeast to consistently meet these requirements. Growers across much of the region may need to switch to varieties with lower chilling requirements—where such options exist.

blueberries and summer-bearing raspberries require anywhere from 700 to 1,200 hours. European wine-grape varieties typically require less than 500 hours, while grapes native to the Northeast (such as Concord) can require closer to 1,800 hours. Cranberries have a particularly high chilling requirement and there are no known low-chill varieties.[20] Thus, warmer winters or an increase in winter thaws or warm spells could reduce spring flowering and yields of these crops even when spring and summer temperatures are optimal for growth.

The NECIA study projected the percentage of years in various time periods this century when winter temperatures in the Northeast would not be sufficiently cold to meet chilling requirements of 400, 1,000, and 1,800 cumulative hours below 45°F. The analysis focused on identifying those areas where chilling requirements would not be met in at least 20 percent of the projected winters—an indicator of significant risk to sustained crop production.[21]

The 1,800-hour chilling requirement affects native grapes such as the Concord. The chilling requirements of cranberries[22] and certain apple varieties such as Northern Spy[23] fall between the 1,000- and 1,800-hour ranges.

- Historically, this relatively high chilling requirement has not been consistently met in southern parts of the region. Over the next several decades, the area that fails to meet this chilling requirement would extend northward into southern New York, Connecticut, and Massachusetts under either emissions scenario.
- By mid-century under the higher-emissions scenario, the 1,800-hour chilling requirement would be met only in northern New England, upstate New York, and small pockets elsewhere in New York and Pennsylvania.
- By late-century, areas meeting this chilling requirement would be restricted under the higher-emissions scenario to the region's higher altitudes and the interior of Maine.

The 1,000-hour chilling requirement affects fruits such as northern blueberry varieties, summer-bearing raspberries, and a number of apple varieties, including McIntosh, Empire, and Granny Smith.[24] In 2005 most of New Jersey's $55 million blueberry crop was produced from a small set of cultivars, all of which require between 800 and 1,000 chilling hours.[25] One thousand hours also represents the low end of chilling-requirement estimates for cranberries (which are thought to require 1,200 to 1,400 hours).[26]

- By mid-century the 1,000-hour chilling requirement would not be met in parts of Pennsylvania and much of New Jersey, Long Island, and southeastern Massachusetts (a key area of cranberry production) under the higher-emissions scenario.
- If lower emissions prevail only southern New Jersey would fail to meet this chilling requirement.
- By late-century this chilling requirement would not be met in New Jersey, much of Pennsylvania, and southern New England under the higher-emissions scenario.
- Under the lower-emissions scenario, most of the region is expected to continue to satisfy this chilling requirement through the end of the century. New Jersey and parts of Pennsylvania, however, would fail to meet this requirement, and southeastern Massachusetts would become increasingly at risk of failing.

Summer heat stress is particularly detrimental to crops adapted to cooler temperatures, such as potatoes and apples, which dominate the Northeast farm economy.

Growers of raspberries and blueberries could potentially adapt to warmer winters by switching to varieties with lower chilling requirements, which were originally developed for production in southern and western states. For long-lived orchard crops such as apples, and varieties with no known substitute such as cranberries, options are currently far more limited.

The 400-hour chilling requirement affects fruits such as European wine grapes and fall-bearing raspberries.

- Yields of crops that require 400 or fewer hours of winter chilling may not be significantly affected by the warming projected for most of the region under either emissions scenario during this century.

Mid-winter warming and temperature variability could spell significant trouble for varieties with chilling requirements on the lower end, as well as the high, since shorter chilling requirements could be fully satisfied in the first part of winter, preparing these plants to leaf out and bloom at the first signal of warm temperatures. Warm spells and thaws such as the shirt-sleeve weather the Northeast experienced in December 2006–January 2007 can cause many varieties of fruit crops, bulbs, and other plant

Maple Syrup: Tapping into Uncertainty

As frigid January temperatures in the Northeast give way to the milder daytime temperatures of late February and March, sap begins to flow in sugar maple trees and another maple syrup season begins. The first sap of the season is particularly important because it often yields the best-quality syrup. Maple syrup production is wholly reliant on climate: in order to make sap, the trees require a period of above-freezing temperatures during the day paired with below-freezing temperatures at night. Recent warming has altered the usual timing of sap production in the Northeast and contributed to a decline in the syrup industry.[27]

The center of maple syrup production has already shifted north from New England into Canada, where climate changes and other factors have improved conditions for syrup production.[28] As a result, Canada is now responsible for 80 percent of the world's maple syrup production compared with the United States' 20 percent market share—proportions that were reversed a few decades ago.[29] As the climate continues to change, the stresses on the Northeast's "sugar makers" will increase.

Vermont currently boasts 44 percent of the region's total maple syrup production, valued at roughly $11 million per year. The industry is one of Vermont's economic mainstays as well as an iconic part of its winter culture, providing seasonal jobs, income to multiple retail and service sectors, and an important draw for tourists.[30]

Possible changes in sugar maple trees

Global warming may affect maple syrup production in this and other syrup-producing states in two important ways. First, warmer temperatures diminish the quantity and quality of sap flow and cause the tapping season to begin earlier and last less long.[31] Syrup producers once depended on tradition to decide when to start tapping; now they must take a gamble: starting at the traditional time may mean missing the first sap (and the finest syrup), while starting too early can result in a shorter season be-

Maple Syrup Producers Face Hard Times

Maple syrup production is highly sensitive to climate. In order to produce sap, sugar maples require a period of above-freezing temperatures during the day paired with below-freezing temperatures at night. During this century, the region's maple syrup industry will face great uncertainty, particularly under the higher-emissions scenario, as both the optimal time for tapping trees and the suitable habitat for sugar maples shift.

cause tap holes eventually clog with bacteria.[32]

Second, climate change may cause a decline in habitat suitability for sugar maple trees. (See the forests chapter.) Sugar maples are well suited to the Northeast's current climate, as evidenced by their abundance and distribution, but suitable habitat is projected to shift northward under the higher-emissions scenario due to rising temperatures and other trends.[33] While this does not mean that sugar maples would rapidly disappear from the region, they could enter a period of decline.

On the other hand, the Northeast's sugar maples may persist in their current range throughout the century due in part to the slow pace at which tree species change their distribution as well as the "fertilizer effect" of increased atmospheric CO_2. Eventually, however, sugar maples may face increased competition from tree species such as oak, hickory, and pine that are better suited to the conditions projected under the higher-emissions scenario.[34] If lower emissions prevail, the Northeast's principal syrup-producing states are likely to remain suitable habitat for sugar maples.

The exact impact of these climate-driven trends on the Northeast's maple syrup industry is not yet clear. Syrup producers are already coping with warmer temperatures by tapping earlier and using new technologies such as plastic tubing and vacuum systems.[35] What is clear is that continued high emissions of heat-trapping gases put this traditional way of rural life at significant risk.

species to break dormancy and bloom prematurely, risking permanent frost damage when winter temperatures plummet again.

Warmer and erratic winters in recent decades have already disrupted the once-predictable arrival of freezing nights combined with warm days that the Northeast's maple syrup producers depend on to sweeten the sugar maples' sap and get it rising in the trees. In fact, the center of maple syrup production has already migrated north into Canada.[36] (See the forests chapter and the text box on maple syrup.)

Heavy spring rainstorms can delay planting and jeopardize profits, particualrly for farmers who are paid a premium for early-season production of high-value horticultural crops.

Rainfall and drought

The Northeast is already experiencing increasingly frequent storms producing heavy precipitation (i.e., more than two inches of rain falling in 48 hours). This trend is projected to continue under either emissions scenario, with the number of such storms increasing 8 percent above historic levels by mid-century and 12 to 13 percent by the end of the century. (See the climate chapter.)[37]

Heavy rainstorms occurring in spring can delay planting and jeopardize profits, particularly for farmers who are paid a premium for early-season production of high-value horticultural crops such as melons, sweet corn, and tomatoes. As these storms occur more frequently, they will likely cause more field flooding, possible crop losses due to a lack of oxygen for plant roots in waterlogged fields, increased crop susceptibility to root diseases, increased soil compaction when heavy farm equipment is used on wet fields, and more runoff and leaching of nutrients and agricultural chemicals into ground and surface water.

Farmers may also need to water crops more because hotter temperatures tend to increase transpiration (the evaporation of water from pores in a plant's leaves). Because climate change is likely to alter both the rate of transpiration and rainfall, the resulting yields for rain-fed grain and silage crops, and irrigation demands for high-value crops such as apples, potatoes, and tomatoes could have a potentially significant impact on the agriculture sector. In 1999, for example, a widespread drought led to net farm-income losses of approximately $1.35 billion nationally—62 percent of which was suffered by the Northeast.[38]

The combination of more precipitation concentrated into heavy rainstorms, little or no reduction in summer and fall rainfall, and increased temperatures is projected to increase the frequency of short-term (one- to three-month) summer and fall droughts under the higher-emissions scenario across New England and the Adirondack region of New York.[39] In these areas, the historic frequency of one short-term drought every two or three years would increase to one such drought per year. More frequent drought during the growing season would increase irrigation demands, particularly for high-value fruit and vegetable crops. (See the climate chapter.)

Direct effects of rising carbon dioxide (CO_2)

Earth's entire food web depends on the ability of green plants to capture CO_2 and solar energy during photosynthesis, enabling the manufacture of carbon-based sugars that facilitate plant growth. The increasing atmospheric CO_2 levels associated with global warming therefore tend to have a fertilizer effect on plants, contributing to more abundant growth. The magnitude and duration of this effect varies tremendously among plant species and varieties, and also depends on many concurrent factors. Early studies conducted primarily under optimal nutrient and water conditions in sheltered chambers and greenhouses found that plants including most of the Northeast's crops (except corn) could benefit from 20 to 30 percent greater productivity when grown at twice the current CO_2 level. However, more recent studies conducted in open fields with CO_2-enriched air have found smaller benefits, often in the range of 10 to 20 percent.[40] Attaining even these modest productivity increases often requires more fertilizer, optimum temperatures, unrestricted root growth, and excellent control of weeds, insects, and disease.

Higher CO_2 levels also exert a potentially water-conserving effect on plants by causing the partial closure of leaf pores, thereby reducing the amount of water lost to transpiration. This effect can be offset, however, by factors such as more prolific leaf growth spurred by higher CO_2 (which would increase water needs).

Atmospheric CO_2 levels are projected to increase during this century from approximately 380 parts per million (ppm) today to 550 ppm under the lower-emissions scenario and 970 ppm under the higher-emissions scenario.[41] The effect of higher CO_2 on plant growth begins to weaken above about 600–800 ppm for most species, so any fertilization benefit that does occur will diminish over time.[42]

Overall, any positive effects of increased CO_2 on plant growth are unlikely to compensate for the negative effects of increased heat stress due to global warming. Field and greenhouse tests with regionally important crop species such as potatoes, dry

Cranberry Harvests at Risk as Temperatures Rise

Massachusetts and New Jersey are among the top national producers of cranberries, supplying nearly half of the U.S. crop. By mid-century under the higher-emissions scenario, it is unlikely that these areas will provide cranberries with the long winter-chill periods required for optimum flowering, fruit set, and seed development. New Jersey is particularly vulnerable under either scenario. Unlike other fruits, no known low-chill variety of cranberry exists.

Kudzu Creeps Northward

Kudzu, a highly aggressive Asian vine that currently infests 2.5 million acres of cropland, fields, and forests in the American South, has already appeared in Connecticut and Massachusetts. The Northeast's cold winters have kept this invasive weed from moving too far north, but warming temperatures should allow it to threaten additional conservation and farmland across the Northeast.

beans, and winter wheat have shown significantly increased yields at twice the current CO_2 level when temperatures are optimal. At higher temperatures (temperatures consistent with those expected under the higher-emissions scenario across southern parts of the region by late-century) there was no benefit from higher CO_2.[43]

WEEDS

Climate determines the suitable geographic range for weeds as well as crops, so changes in temperature and rainfall will likely alter both the mix of weed species in the Northeast and their competitive abilities. Evidence also suggests that rising CO_2 will generally spur greater growth in weeds than in crops.[44,45] Furthermore, higher CO_2 seems to reduce the effectiveness of widely used herbicides, which could spur increased chemical use.

Controlling weeds costs the United States more than $11 billion annually, with the majority spent on herbicides.[46] In the Northeast alone, annual farm expenditures for pesticides and herbicides currently amount to $199 million.[47]

Of particular concern to regional agriculture is the possibility that warmer temperatures may allow the northward spread of invasive weeds that already cause major crop losses to the South. Southern farmers already suffer substantially larger crop losses to weeds than northern farmers—35 versus 22 percent for corn and 64 versus 22 percent for soybeans.[48] The northward range of some extremely aggressive weeds plaguing southern farmers (such as kudzu, witchweed, cogongrass, and itchgrass) is confined to areas where winter temperatures do not drop below specific temperature thresholds (e.g., -4°F; see below).[49]

The U.S. Department of Agriculture has spent millions of dollars over the past 50 years to eradicate and prevent the spread of witchweed, a native of Africa and Asia that damages corn and sorghum. Kudzu, which currently infests 2.5 million acres of the Southeast and is a carrier of the fungal disease soybean rust, represents a major threat to U.S. soybean production. It has already appeared in Connecticut and Massachusetts in recent years, and warmer winter temperatures should allow it to colonize other parts of the Northeast—threatening conservation land as well as farmland.

NECIA analyses projected a northward shift in the -4°F boundary for suitable invasive-weed habitat under both emissions scenarios.[50] By mid-century the potentially habitable zone for kudzu and other invasive weeds includes most of Connecticut, Massachusetts, New Jersey, Pennsylvania, Rhode Island, and the lower half of New York under either scenario. By the end of this century it also encompasses most of New Hampshire, New York, Vermont, and the lower half of Maine under the higher-emissions scenario, but is constrained from expanding further under the lower-emissions scenario.[51]

In terms of the fertilizer effect of CO_2, weeds are more likely than crop plants to take advantage of increases in this resource.[52] In all studies of weed-crop competition where the two plants use the same photosynthetic pathway, for example, rising CO_2 favored weed growth.[53] Furthermore, in the typical agricultural setting where there are many more weed species than crop species, at least some of the weeds are likely to be more responsive to CO_2 than the crop. Fresh sweet corn in Pennsylvania, for example, typically contends with eight different weed species that use one of two photosynthetic pathways. A recent study of soybean fields found that increased CO_2 favored the primary weed (lambsquarters).[54]

Rising levels of CO_2 in the atmosphere will generally spur greater growth in weeds than in crops.

Farmers in the Northeast apply 9 million pounds of herbicides to their fields each year.[55] Unfortunately, an increasing number of studies indicate that effective and widely used herbicides such as glyphosate (marketed as RoundUp) decline in efficacy as CO_2 levels rise.[56] Weeds may still be controlled with additional sprayings or stronger concentrations of the herbicide, but this will almost certainly increase both the economic and environmental costs of chemical use. The additional expense may represent a significant burden for marginally profitable farmers.

Field tillage can cut weeds off at the roots, but this practice may also become less effective (or even counterproductive) if rising CO_2 spurs increased root growth in weeds such as Canada thistle that propagate from small root segments. For the expanding organic farming sector, which controls weeds using farm labor rather than herbicides and pesticides,[57] an increase in aggressive weeds may mean more costly, labor-intensive weed removal and potentially lower yields.

INSECT PESTS

Continued warming and milder winters will likely allow more southerly insect pest species to move north, increase the survival rate of insect pests that spend the winter in the Northeast, and worsen outbreaks of such pests. Global warming may also spur the earlier arrival of migratory insects and allow some species to produce more generations within a single season. For example, fruit pests such as the apple maggot, oriental fruit moth, codling moth, and plum curculio currently produce more generations in warm southern regions of the United States than in the Northeast. Studies conducted in Western Europe and elsewhere have already documented climate-driven changes in the geographic distribution and spring arrival of insect species.[58,59,60] Plant-feeding pests may also eat more and cause greater crop damage as rising CO_2 lowers the nutritional value of plant tissues.[61]

Annual pesticide use in the Northeast is currently estimated at more than 12 million pounds.[62] Just as with weeds, increasing pest outbreaks and crop damage

Opportunity and Risk in the Future of Northeast Farming

Farmers in the Northeast face new opportunities and risks in a warmer climate. Rising temperatures and a longer growing season would allow new crops to be grown in areas with a currently short growing season (as on the shores of Vermont's Lake Champlain, shown here), while exposing the region to new threats to traditional crop production. Who gains and loses in the farming sector may depend on who can invest most heavily in response to changing climate conditions.

will quite likely lead to greater use of chemical controls and an increased risk of environmental damage.

Warmer winters in the Northeast can be expected to increase the populations of marginally overwintering insect species such as corn earworms and the flea beetles that carry Stewart's wilt (a bacterial disease that can ruin corn crops). Currently, only the southernmost parts of Pennsylvania and the southern half of New Jersey experience moderate to severe flea beetle pressure in a typical year. A NECIA analysis used climate projections for both emissions scenarios as input to a flea beetle/Stewart's wilt "severity index" model commonly used by integrated pest-management programs to predict the severity of such outbreaks on an annual basis.

- By mid-century the suitable habitat zone for flea beetle/Stewart's wilt is projected to extend significantly farther north under both emissions scenarios, threatening the profitability of widely grown sweet and field corn.
- By the end of this century all of the Northeast except for a small portion of northern Maine could experience consistently severe pressure from flea beetle/Stewart's wilt outbreaks under the higher-emissions scenario. Pest pressure would also increase considerably under the lower-emissions scenario. Actual pest pressure would depend, among other factors, on whether corn is grown in vulnerable areas.

It is reasonable to assume that other insect pests will similarly increase in population and expand in range as the Northeast warms. An increasing number of outbreaks of a wider variety of insects would likely boost pesticide use by farmers in the region; there is already a clear trend of greater pesticide use on crops in warmer southern regions of the United States than on the same crops in the Northeast. For example, Florida sweet corn farmers spray their fields anywhere from 15 to 32 times a year to control insect pests such as European corn borer and corn earworm, while New York farmers average zero to five times. Also, just as higher levels of CO_2 lower the efficacy of some herbicides, higher temperatures reduce the effectiveness of certain classes of pesticides (pyrethroids and spinosad).

Organic farms, which invest more in labor-intensive pest control, tend to grow a more diverse set of crops that may be less vulnerable to increasing insect pest populations. As the climate changes, the agriculture sector as a whole may require more frequent review and updating of pest monitoring and integrated pest management practices.

ADAPTING TO UNAVOIDABLE CLIMATE CHANGE

For farmers faced with a changing climate, the "first line of defense" may involve new planting dates, harvest dates, and/or crop varieties. Unfortunately, such strategies are never risk- or cost-free, and many small family farms may lack the profit margins and capital to experiment with such changes. These strategies may be inadequate to overcome losses caused by more extreme changes in climate. For example, although studies have shown that delaying potato planting for two weeks in some regions can effectively prevent crop-yield reductions associated with warming of 3°F to 4.5°F, no planting delay can compensate for warming of 9°F.

Switching perennial crop varieties such as grapes or apples involves a transition of several years in which the farmer can expect no or low productivity. Even for annual crops, switching varieties may require investments in new field equipment or changes in farming practices. And because a systematic evaluation of different varieties' adaptability to heat, drought, and higher CO_2 has not yet been undertaken, there are few known options for varieties better suited to changing conditions in the Northeast. Farmers must also anticipate market acceptance of the color, size, shelf life, and other qualities of newly introduced varieties.

Beyond these first-line strategies, adaptation to global warming may involve large capital investments in irrigation systems, crop-storage or livestock facilities, or other technologies that may be affordable for wealthy farmers and corporate enterprises but less accessible to many of the small family farms still common in New England. Finally, climate change may provide an incentive for farming operations of all sizes to take advantage of some "win-win" opportunities—strategies that benefit farmers and the environment simultaneously, such as increasing organic matter (mostly carbon) in soils, using nitrogen fertilizers more efficiently, conserving energy, and using marginal land to produce renewable energy such as biomass fuels or wind power. (See the Meeting the Climate Challenge chapter.)

CHAPTER SIX

Impacts on Winter Recreation

KEY FINDINGS

- **Global warming is projected to profoundly affect winter recreation and tourism in the Northeast as winter temperatures continue to rise and snow cover declines, especially under the higher-emissions scenario.**
- **Snowmobiling is the most vulnerable of the region's economically important winter recreation activities because, unlike the ski industry, it cannot rely on machine-made snow. Within the next several decades, snowmobiling opportunities are projected to become virtually non-existent in Pennsylvania and western and southeastern New York under either emissions scenario used in this assessment.**
- **By late-century, average season length across the region is projected to decline to 13 days under the higher-emissions scenario, an 80 percent decline below recent levels, and to 25 days under the lower-emissions scenario, a 57 percent decline. Only northern New Hampshire would retain a snowmobile season longer than two months if higher emissions prevail.**
- **Warmer winters would also shorten the average ski and snowboard seasons, increase snow-making requirements, and drive up operating costs (particularly under the higher-emissions scenario). This may prompt further closures and consolidation of ski areas northward toward the Canadian border.**
- **Under the higher-emissions scenario, only the northern New England states and the North Country of New York are projected to support viable ski operations by mid-century. By the latter part of the century, only western Maine is projected to retain a reliable ski season under the higher-emissions scenario.**
- **Under the lower-emissions scenario, reliable ski seasons can be expected through this century in the North Country of New York and parts of Vermont and New Hampshire, in addition to western Maine.**
- **These projections may be conservative, as the climate models used in this analysis have consistently underestimated the rapid winter warming and snowpack decline observed in recent decades.**

BACKGROUND

As the Northeast's climate changes, so will the length and quality of its outdoor-recreation seasons. Winter snow and ice sports, which are worth some $7.6 billion annually to the regional economy, will be particularly affected.[1] Of this total, alpine skiing and other snow sports (not including snowmobiling) account for $4.6 billion annually.[2] Snowmobiling, which now rivals skiing as the largest winter recreation industry in the United States, accounts for the remaining $3 billion.[3,4,5] Other winter traditions, ranging from skating and ice fishing on frozen ponds and lakes to cross-country (Nordic) skiing, snowshoeing, and dogsledding, are integral to the character of the Northeast and, for many, its quality of life.

Global warming is projected to bring about a

Warmer Winters Threaten Favorite Pastimes

From skiing and snowboarding to snowmobiling, ice fishing, and sledding, many residents of the Northeast embrace winter recreation. But the region's winters are warming. Over the course of this century more winter precipitation is projected to fall as rain, and snow and lake ice is expected to melt more quickly, reducing opportunities for popular winter activities.

dramatic decline in the average number of snow-covered winter days across the Northeast, especially under the higher-emissions scenario. By the end of the century the northern part of the region is conservatively projected to have lost more than one-quarter of its snow-covered days under the lower-emissions scenario and up to half of its snow-covered days under the higher-emissions scenario.[6] (See the climate chapter.) Winter activities such as snowmobiling, cross-country skiing, snowshoeing, and sledding that depend primarily on natural snow cover will be most vulnerable to this decline.

Most previous assessments of the vulnerability of winter recreation to global warming have not examined the impacts on snowmobiling or the ability of the ski industry to adapt through increased snowmaking. These factors were, however, primary considerations in this assessment of the Northeast's winter recreation/tourism sector.[7] Ski resorts in the region have invested heavily in snowmaking technology over the past two decades to address year-to-year variations in natural snowfall and extend the skiing season. By the 2004–2005 ski season, 75 percent of the Northeast's skiable terrain had been augmented with snowmaking equipment, which allowed resorts to extend their seasons compared with the 1980s—despite winters in the 1990s that were the warmest on record.

A recent study of winter recreation in New Hampshire over the past two decades of highly variable snowfall found (not surprisingly) that more people participate in outdoor recreation when winters are cold and snowy.[8] Tourism earns the state $4 billion a year, and although winter visitors represent less than one-quarter of all tourists, they spend almost 19 percent more per day than the average tourist because of the expensive natures of skiing and snowmobiling. Winters with above-average snowfall attract 14 percent more alpine skiers, 30 percent more Nordic skiers, and 26 percent more resident snowmobilers (i.e., those buying snowmobile licenses) to New Hampshire's winter recreation areas, largely concentrated in the northern part of the state. This in turn translates into an extra $13 million in ski-lift tickets and snowmobile registration fees. Snowy winters also generate about 3,000 more jobs in the state than less snowy ones.[9]

The overall impact of climate change on the

Northeast's tourism economy will of course depend not only on declining winter recreation opportunities but also on potentially expanding opportunities for many warm-season activities such as golfing, hiking, all-terrain vehicle (ATV) riding, boating, fishing, and beach use. In 2006, for example, New Hampshire purchased 7,500 acres of land to establish a state-run ATV park (one of the few north of Pennsylvania).[10] Such developments may provide a glimpse of the recreation-tourism sector's future responses to unavoidable warming.

SNOWMOBILING

Snowmobiling is arguably the largest winter recreation industry in the United States,[11,12] and the Northeast boasts some of the nation's densest trail networks. The six states of Maine, Massachusetts, New Hampshire, New York, Pennsylvania, and Vermont together account for 30 percent (about 40,500 miles) of U.S. snowmobile trails, which generate $3 billion a year.[13]

Because of the costs and logistical impracticality of installing and operating snowmaking systems on hundreds or thousands of miles of trails, snowmobiling (like cross-country skiing and snowshoeing) relies almost entirely on natural snowfall. Consequently, the sport is highly sensitive to the vagaries of climate—as illustrated by the winter of 2005–2006, when record warmth early in the season delayed the opening of many snowmobile trails across New York, Vermont, and other parts of the eastern United States and Canada until late February. Similarly balmy days delayed the following snowmobile season as well.[14]

NECIA analyses ran climate models using both the higher- and lower-emissions scenarios to project changes in natural snow depth and, thus, the average length of the snowmobiling season and the geographic extent of snowmobiling-suitable conditions over the rest of this century.[15] In recent decades, the length of the snowmobiling season has ranged from less than a month in Pennsylvania to more than three months in northern New York and New England. Many observers see two months as the minimum length of a reliable snowmobiling season.[16] Under both scenarios, climate models project a trend toward much shorter snowmobiling seasons and a northward shift in suitable conditions, with swifter and more widespread contraction of the season under the higher-emissions scenario.

- Within the next several decades, more southerly snowmobiling areas, such as those in Pennsylvania and western and southeastern New York, are projected to see snowmobiling opportunities become virtually non-existent under either emissions scenario.[17]
- By mid-century under the higher-emissions scenario, the snowmobiling season is projected to decline by 65 percent on average below historic levels. In southern New Hampshire, the average season length is projected to decline from 45 to 8 days. Only areas in northern New England are projected to retain an average snowmobile season of two months or more.
- By mid-century under the lower-emissions scenario, an average 50 percent decline in season length is expected across the region. In addition to northern New England, north-central New York is projected to retain a minimum two-month-long season.
- By late-century, regionwide reductions in season length of nearly 80 percent are projected under

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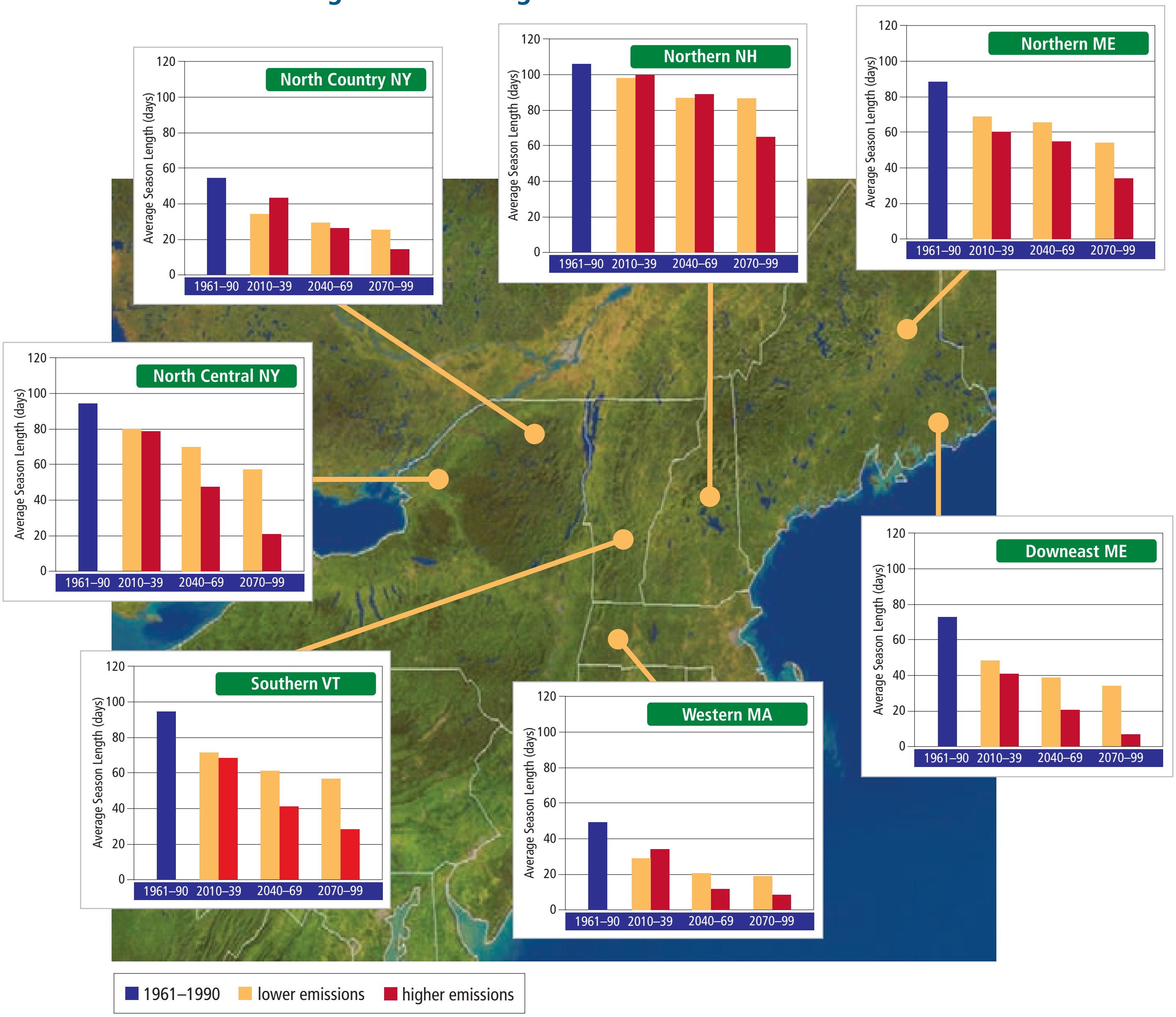
Because of the costs and logistical impracticality of making snow on hundreds of miles of trails, snowmobiling, cross-country skiing, and snowshoeing rely on natural snow.

Snowmobiling Opportunities Disappear

Teenagers in Southington, CT, zip through the snow. The New England states, together with New York and Pennsylvania, account for 30 percent of U.S. snowmobile trails and $3 billion in annual revenue. Snowmobiling generally requires six inches of snow or more on the ground, but the number of days offering these conditions is projected to decline steeply over the course of this century. Because of the impracticality of snowmaking over such an extensive network of trails, the snowmobile season may become virtually non-existent in all but the region's northernmost states.

FIGURE 10: **Shrinking Snowmobiling Seasons**



The snowmobiling season has already begun to see declines in recent years as winters have warmed and natural snow cover has diminished. This trend is expected to continue in the coming decades under both the lower- and higher-emissions scenarios, but with faster and farther-reaching changes under higher emissions. Projected season-length changes in six of the 15 snowmobiling areas studied are presented here. By mid-century, only northern areas with historically long snow-mobiling seasons are expected to retain sufficient snow for a two-month season or longer.

Ice Fishing: A Threatened Tradition

Ice fishing derbies are a winter institution in parts of the Northeast, bringing well-bundled anglers out to drill holes through the ice of frozen lakes and wait for perch, pickerel, pike, bass, trout, or tiger muskie. But the Northeast's winters—and its ice fishing—are not what they used to be.

In 2007 the New York State Crappie Derby was canceled for the second year in a row because the ice on Whitney Point Lake in mid-January was so thin that the contest's sponsors feared for anglers' safety. A similar fate befell that year's Berkshire Wild Turkey Federation Derby on Lake Buel in western Massachusetts, while many others were postponed into February.[18,19,20]

As winters have warmed over the past century, the duration of ice cover on the region's lakes has decreased. "Ice-in" dates (when the majority of a lake or pond has frozen over) have been occurring later in winter while ice-out dates (when ice cover has largely melted) are arriving earlier in spring. The duration of ice cover on southern Maine's Sebago Lake, for example, has declined by two weeks since the mid-nineteenth century, and the rate of decline has accelerated over the past 25 years. In addition, the once-rare years when Sebago Lake fails to freeze at all are occurring more frequently.

The same is true of Lake Champlain on the New York-Vermont border, which has failed to freeze over in a dozen winters since 1970. On Lake Winnipesaukee in the White Mountains of New Hampshire, the average ice-out date now occurs eight days earlier than a century ago; further north on Maine's Moosehead Lake and Rangeley Lake, ice is breaking up six days earlier. Overall, ice-out dates now average nine days earlier in the northern and mountainous parts of the Northeast and 16 days earlier in the southern parts.[21] Global warming is expected to further thin lake ice cover and shorten its duration.[22]

These changes not only affect ice fishing but also skating, snowmobiling, cross-country skiing, dogsled racing, and other ice activities that have long been a part of the Northeast's way of life—and a source of winter income for many small towns. Decreasing lake ice may also affect fish habitats in lakes and rivers. (See the forest chapter and the text box on coldwater fish.)

Lake Ice and Winter Fishing Opportunities in Decline

As the Northeast's winters have warmed over the past century, the duration and thickness of ice cover on its lakes (such as Lake Champlain, pictured here) has decreased, threatening the popular winter pastime of ice fishing. Global warming is expected to advance this trend.

Snowmaking Needs and Costs to Increase

Warming winters have increased the amount of snowmaking required at ski resorts throughout the Northeast (such as this one in Haverhill, MA). This trend is projected to increase under either emissions scenario, but many resorts could experience conditions too warm for snowmaking under the higher-emissions scenario.

the higher-emissions scenario, but roughly 55 percent under the lower-emissions scenario. Only northern New Hampshire would retain a snowmobile season longer than two months if higher emissions prevail.

Some snowmobiling enthusiasts may switch to ATVs, which are not dependent on snow conditions.

The implications of these changes will depend heavily on the response of the snowmobiling community itself. Across the Northeast, the industry relies on a network of volunteers to clear and groom trails and inform the public about trail conditions. If a series of very short seasons causes a loss of enthusiasm and volunteers, communities may not be able to maintain nearby trails. In addition, lower membership in local snowmobiling clubs and lower sales of trail permits would mean less money to invest in grooming equipment and trail maintenance, which are needed even more when snow conditions are marginal. Poorly groomed or maintained trails could accelerate a decline in participation. If, however, snowmobilers in the Northeast continue to participate in the sport in the same or only slightly reduced numbers, then the parts of the region that maintain sufficient natural snow and well-maintained trails may potentially benefit from increased concentration of snowmobile tourism.

Some snowmobiling enthusiasts may switch to ATVs, which are not dependent on snow conditions. In the past five years U.S. ATV sales have grown while snowmobile sales have declined, suggesting that the transition is already under way in some regions. A large switch from snowmobiling to ATV use would have important implications for land managers and communities in the Northeast since ATVs tend to have far more damaging impacts on vegetation and recreational trails. Some snowmobiling-dependent communities are already debating whether to allow ATVs on snowmobile trails in low- or no-snow years.[23]

Concerns about snowmobiling apply, to a certain extent, to other activities that depend almost entirely on natural snow cover, such as cross-country skiing, sledding, and snowshoeing. Because the time and financial investment required to participate in these activities tends to be significantly lower than snowmobiling, they could persist as recreational activities despite a shortened or unreliable season, but the income these activities generate is unlikely to compensate for the income lost due to a decline in snowmobiling.

SKIING

The Northeast's ski resorts represent one-fourth of the U.S. skiing and snowboarding market, hosting 13.6 million skier-days in the winter of 2004–2005.[24] The economies of New Hampshire and Vermont, in particular, are heavily skiing-dependent: Vermont's resorts generate more than $1.1 billion annually; New Hampshire's generate $650 million.[25,26]

To sustain this industry during the warm winters and extreme year-to-year variations in snowfall of the 1990s, the region's ski resorts continued their massive investments in snowmaking systems. A 100-day season is commonly used as a benchmark for the continuing profitability of ski resorts, and between the winters of 1990–1991 and 2004–2005 the Northeast's ski season varied between 101 and 146 days. During the same period, expanded snowmaking capabilities actually increased the average season length compared with the 1980s, staying above 120 days despite record warmth. By the 2004–2005 season, three-fourths of the skiable terrain in the region was augmented by machine-made snow. In December 2006 and January 2007, however, temperatures were so warm that it was difficult for ski resorts to even make snow.

Whatever the season length, not all days are equally profitable. The most important revenue-generating period for the Northeast's ski resorts is the Christmas–New Year's holiday, which can generate as much as one-third of their annual revenues.

To assess the impact of global warming on the Northeast's ski industry, NECIA analyses projected changes in ski-season length, probability of being open during the Christmas–New Year's holiday, and snowmaking requirements. Areas with both a projected average season of less than 100 days and a less-than-75-percent probability of operating during the holiday period are defined as "highly vulnerable" to climate change.

- Under either emissions scenario ski areas in Connecticut, western and southeastern New York, and eastern Pennsylvania are projected to be highly vulnerable within the next several decades.
- Under the higher-emissions scenario additional areas—including southeastern Maine and eastern Massachusetts—are projected to be highly vulnerable by mid-century.
- Only a few areas are projected to have ski seasons longer than 100 days and reliable holiday operations by late-century.
  — Under the higher-emissions scenario only western Maine is projected to meet these criteria.
  — Under the lower-emissions scenario western Maine, northern New Hampshire, northeastern New York, and southern Vermont would meet these criteria.

The fate of resorts in these areas will depend in part on whether people living to the south are willing to travel longer distances to ski.

Global warming is projected to require substantial increases in snowmaking (and the associated costs) throughout the region. Eight of the 14 areas studied are projected to require at least 25 percent more machine-made snow in the next couple of decades. Under the higher-emissions scenario the four ski areas able to maintain an average ski season longer than 100 days by late-century would require at least 75 percent more snowmaking, and three of these—western Maine, northern New Hampshire, and southern Vermont—would require more than a 100 percent increase. In some more southerly areas conditions are projected to become too warm to reliably and efficiently make snow.

Under the lower-emissions scenario many remaining ski areas are expected to require 50 percent more snowmaking than today. Besides having to make more snow, ski areas may have to pay more for the privilege because the snow will need to be made at warmer temperatures, which requires more energy.

Unreliable Conditions on the Slopes

Poor trail conditions that have plagued Northeast resorts in recent winters may be here to stay, with ski areas in Connecticut, southern New York, and parts of Pennsylvania facing the loss of a reliable ski season in the next several decades.

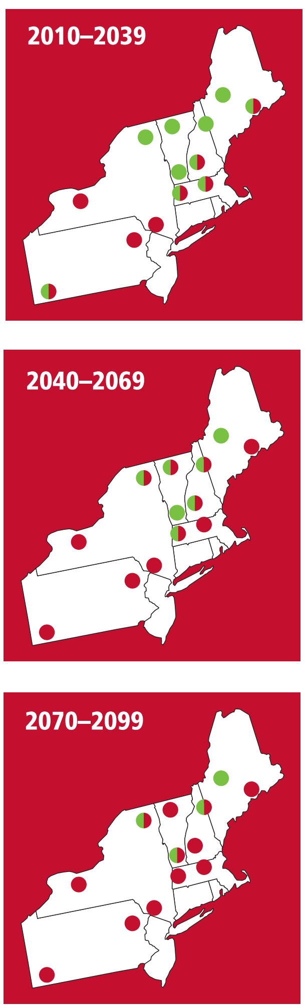
TABLE 4: **Driving Distance to Nearest Major Ski Resort**

Starting Location	Today	2070–2099 (under the higher-emissions scenario)
New York City	90 miles (Holiday Mountain, NY)	220 miles (Bromley Mountain, VT)
Philadelphia	80 miles (Blue Mountain, PA)	290 miles (Mt. Snow, VT)
Pittsburgh	60 miles (Seven Springs, PA)	500 miles (Gore Mountain, NY)
Trenton, NJ	90 miles (Blue Mountain, PA)	260 miles (Mt. Snow, VT)

This table lists ski resorts located in areas considered in the NECIA winter recreation analysis. Closer viable operations may exist at present. Listed destinations are projected to be viable under the lower-emissions scenario but "vulnerable" if higher emissions prevail.

FIGURE 11: **Vulnerability of Ski Resorts to Climate Change**

Higher Emissions



Ski resorts in "highly vulnerable" areas (red) are projected to fail to meet two criteria for sustainability (season length greater than 100 days, and high probability of being open during the profitable Christmas–New Year's holiday period). Those in "vulnerable" areas (red and green) are projected to fail to meet one of these criteria, and those in "viable" areas are projected to meet both criteria. Under lower emissions, several additional areas (northern New Hampshire, northeastern New York, and southern Vermont) are projected to retain viable resorts.

- highly vulnerable
- vulnerable
- viable

Although global warming will shorten the average ski season and increase snowmaking requirements and costs throughout the region, individual ski resorts and communities face a much greater risk than the industry as a whole, which could respond to climate change by accelerating the existing trend toward contraction and consolidation of resorts. Thus, while warmer winters would contribute to the demise of some ski resorts, the market share of surviving resorts could improve.

If the total number of skiers remains relatively stable, skiing-related businesses in western Maine, northern New Hampshire, northeastern New York, and Vermont might benefit economically from reduced competition. This assumes, however, that these resorts have access to the increased volume of water that will be required for snowmaking—a factor that could exacerbate conflicts over water use in some areas. Furthermore, regardless of a ski resort's snowmaking potential, the results of one recent study[27] reinforce the perception of many industry professionals that people from the cities and suburbs will be less likely to go skiing if there is no snow on the ground where they live. Significant increases in driving distances to viable ski resorts (Table 4) would discourage participation by increasing the cost and time involved.

CONCLUSION

The character of winter recreation in the Northeast may change greatly over the course of this century as the region warms, snowmaking becomes more challenging, and natural snow cover and lake ice become increasingly rare. Changes projected under the lower-emissions scenario are significant, but the swiftness and extent of change expected with higher emissions serve to remind us that this sector depends greatly on current and future emissions.

Vermonters, age 12 and 11, ice fish in 1997, pulling in perch and rainbow trout. Winter recreation opportunities could change dramatically in the lifetime of young residents of the Northeast, depending on emissions choices made now and in the next several years.

CHAPTER SEVEN

Impacts on Human Health

KEY FINDINGS

- **The Northeast is projected to experience dramatic increases in extremely hot days over the coming century (particularly under the higher-emissions scenario), increasing the risk of heat-related illness and death among vulnerable populations, especially in urban areas.**
- **Under the higher-emissions scenario, for example, Pittsburgh and the Concord/Manchester area of New Hampshire could each experience roughly 25 days over 100°F every summer by the end of the century, and typically cooler cities such as Buffalo could average 14 such days.**
- **Global warming could worsen air pollution in the Northeast, creating more days when national air-quality standards cannot be met (particularly under the higher-emissions scenario). Deteriorating air quality would exacerbate the risk of respiratory, cardiovascular, and other ailments in states such as Massachusetts, which already has the highest rate of adult asthma in the United States.**
- **In the Philadelphia metropolitan region, for example, the number of days failing to meet the federal ozone standard is expected to at least quadruple by late-century under the higher-emissions scenario if local vehicle and industrial emissions of ozone-forming pollutants are not reduced.**
- **Rising temperature and CO_2 levels could worsen pollen-based allergies across the Northeast, particularly under the higher-emissions scenario.**
- **Hotter, longer, drier summers punctuated by heavy rainstorms may create favorable conditions for more frequent outbreaks of mosquito-borne diseases such as West Nile virus.**

BACKGROUND

Global warming is expected to increase the risk of many types of weather- and climate-related illnesses—and death—for people living in the Northeast. The IPCC's latest assessment of such risks across all of North America[1] found that urban areas will likely suffer more severe and longer heat waves, leading to a greater incidence of illness and death, particularly among the elderly and other vulnerable populations. On the other hand, northern cities are also likely to experience milder winters, potentially reducing cold-related illness and death. The IPCC noted as well that lung-damaging air pollution from ground-level ozone could be exacerbated by a warmer climate, as could levels of airborne pollen. This may cause an increase in respiratory disorders such as asthma.

In addition, outbreaks of many infectious diseases are related to particular types of weather that will be affected by global warming. Waterborne diseases, for example, often coincide with extreme rainstorms, heavy runoff, and warmer temperatures. The range and incidence of vector-borne diseases (i.e., those transmitted from animals to humans by mosquitoes and ticks) such as West Nile virus and Lyme disease also vary with fluctuations in climate. The IPCC projects that Lyme disease-carrying ticks could shift northward and other vector-borne diseases could expand their range as winter temperatures rise. Finally, many coastal regions are expected to face greater risks to human life and property from rising sea levels, higher storm surges, and changes in the incidence and severity of flooding.[2]

Millions of People Live and Work in Northeast Cities

Nearly 14 million people live in the urban centers of the Northeast—and everyone feels the heat when summer temperatures soar. Projected increases in extreme heat and potential reductions in air quality, especially under the higher-emissions scenario, could lead city dwellers and visitors alike to curtail time spent outdoors.

In the Northeast, the impact of global warming on heat- and air pollution-related illness and death has become a topic of increasing public concern. Projecting how climate change may alter the frequency and severity of heat waves and exacerbate ground-level ozone pollution in the region's major cities was a principal focus of the NECIA modeling conducted for this analysis. NECIA analyses also examined the potential for climate-driven changes in airborne pollen and the incidence of vector-borne diseases in the Northeast.

EXTREME HEAT

When we think of weather-related injuries and deaths, tornadoes and hurricanes most often come to mind as the primary culprits, rather than hot, sticky summer days. Yet in six out of 10 recent years (between 1993 and 2003) heat was the leading weather-related killer in the United States. From 1999 to 2003 the nation reported 3,442 heat-related deaths, two-thirds of which were directly caused by exposure to extreme heat (heat was a contributing factor in the other third).[3] In 1995 a five-day heat wave in Chicago generated maximum temperatures ranging from 93°F to 104°F and caused an estimated 700 deaths.[4] This event was an unwelcome preview of the temperature extremes and public-health challenges that are expected to intensify with global warming.

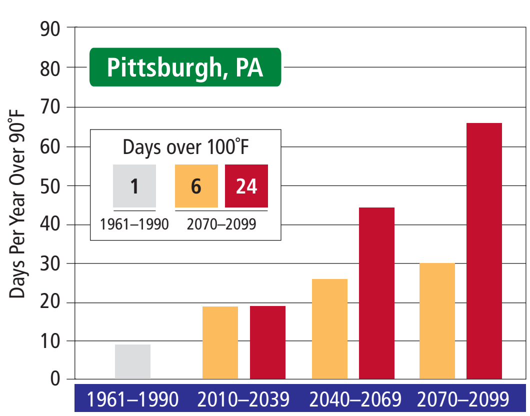
For example, as the entire nation sweltered during the summer of 2006, New York City experienced two heat waves—a three-day period in July and a 10-day period in July and August when maximum temperatures soared to 90°F or higher each day—that produced the city's highest death toll from heat stroke in more than half a century. Of the 46 people who died, more than 80 percent were age 50 or older, 68 percent had multiple medical conditions (most often including heart disease), and only two people had working air conditioners. When city health officials looked beyond deaths directly related to heat stroke, they estimated that the excessive heat during the second heat wave drove the death rate from natural causes 8 percent higher than on normal summer days—translating into the premature deaths of 100 people during the 10-day event.[5]

Heat waves are most dangerous in urban areas because of the large concentration of potentially vulnerable people (see the text box on social vulnerability and cities) and the so-called urban heat-island effect, which drives both day and nighttime temperatures higher in cities than in suburbs and rural areas. The effect occurs mainly because pavement and buildings absorb and retain the sun's energy more effectively than fields and forests.

The effects of extreme heat and poor air quality on human health already represent a growing problem for the Northeast, which now experiences on average two more days each summer with temperatures exceeding 90ºF than in 1960. Currently, northeastern cities experience an average total of five summer days over 90ºF in the northern part of the region and up to 20 such days in the more southerly and inland areas. In terms of days over 100ºF, some cities including Buffalo do not currently experience even one such day per summer while New York City and Philadelphia experience an average of two.

Over the coming century, however, the number of such extremely hot days is projected to increase for the seven important northeastern cities (Boston; Buffalo; Concord/Manchester, NH; Hartford; New York City; Philadelphia; and Pittsburgh) that were

FIGURE 12: Increases in Extreme Heat in Northeast Cities



The number of days over 90°F in large northeastern cities is projected to increase in the coming decades until, by late-century, some cities could experience nearly an entire summer of such days under the higher-emissions scenario. Projections under this scenario also show a dramatic increase in the currently small number of days over 100°F (as depicted in the inset boxes).

the focus of NECIA research, most dramatically under the higher-emissions scenario.[6]

- By mid-century most cities are projected to experience an additional 20 to 40 days per year over 90ºF under the higher-emissions scenario. Under the lower-emissions scenario an additional 10 to 20 such days are projected—still a substantial increase.
- By the end of the century many of these cities are likely to experience a total of more than 60 days each year with temperatures over 90ºF under the higher-emissions scenario. Buffalo, one of the more northern cities, is projected to experience nearly 50 such days per year while Philadelphia is projected to experience 82 such days. Under the lower-emissions scenario most northeastern cities are projected to experience at least 30 days per year over 90ºF by century's end.
- The number of days per year over 100ºF is likely to be at least 20 by the end of the century under the higher-emissions scenario and closer to 30 in some cities (such as Philadelphia and Hartford). If lower emissions prevail, however, the number of such extremely hot days is projected to be far smaller, ranging from three in more northern cities up to nine in more southern cities.

Of course, how hot we feel in summer is a function of both temperature and humidity; these are often reported together in terms of heat index. For example, the average daily summer heat index for Maine is currently 81ºF; for New Jersey it is 90ºF. In other words, this is how hot summers *feel* in these states.

By mid-century most Northeast cities are projected to experience an additional 20 to 40 days per year over 90°F if higher emissions prevail.

Heat index can also be used to project changes in future summer climate. When both rising temperature and humidity are considered, future summers are likely to feel much hotter than what the thermometer indicates. Under the higher-emissions scenario, for example, people in the Northeast can expect late-century summer days to feel 12°F to 16ºF hotter for the projected increase in average summer temperatures of 6°F to 14ºF. (See the climate chapter.)

Globally, as temperatures rise, a reduction in cold-related deaths can be expected,[7] but in temperate regions of the world (where populations are typically more prone to heat- than cold-related deaths), such as the Northeast, this reduction will likely not be large enough to offset heat-related mortality.[8,9]

Children, the Elderly, and the Poor Are Most Vulnerable to Extreme Heat

Very hot days can be more than unpleasant; they can be extremely dangerous. As the number of these days increases (most dramatically under the higher-emissions scenario) so does the risk of heat stress and even death. To lessen the impact on the region's most vulnerable people—children, the elderly, and the poor—cities and towns across the region must improve their preparations for coping with extreme heat.

With an aging population, aging infrastructure, and a health-care system already under strain, the Northeast faces a serious threat from these projected increases in extreme heat, particularly under the higher-emissions scenario. If emissions go unchecked, the number of days over 90ºF in many cities is projected to triple or quadruple by mid-century. The difference between emissions scenarios is best exemplified by the projected increase in dangerously hot days over 100ºF, which can be largely avoided if we move swiftly onto a path of lower emissions. (See the Meeting the Climate Challenge chapter.)

Vulnerability and adaptation

In light of the United States' rapidly growing elderly population, more and more people will become vulnerable to heat stress. In 2003, people older than 65 represented roughly 12 percent of the U.S. population and, of these, about 80 percent had at least one chronic health condition.[10] By 2030 this age group is expected to nearly double in size (to roughly 20 percent of the population). The Northeast's population is already somewhat older than the rest of the country: nearly 14 percent of residents are older than 65. Moreover, this aging population resides in cities and towns that have not consistently coped well with the heat waves the region has seen to date.[11]

As the population ages, the demand on health-care facilities will increase, and the additional effects of climate change could intensify that demand in the coming decades. A recent report on the state of U.S. emergency-room care concluded that the system is "overburdened and underfunded" and "lacks stability and the capacity to respond to large disasters or epidemics."[12] Against today's backdrop of limited capacity in the health-care system, the added burden of climate change is cause for concern.

How many people are likely to suffer or die in dangerously hot conditions depends not only on the specific temperature and their amount of exposure and degree of sensitivity to heat, but also on how well equipped they are to cope. In other words, people can adapt to increases in extreme heat through air conditioning, better insulation, expanded public health education, implementation of warning systems, and increased access to cool public spaces. Heavier reliance on measures such as air conditioning, however, could have the negative effect of increasing heat-trapping emissions.

As of 2001 only 14 percent of homes in the New England states had central air conditioning, while an additional 44 percent utilized single-room units. Overall, 58 percent of New England homes had some form of air conditioning, compared with 77 percent of homes nationwide.[13] As a result heat-related deaths are often lower in southern cities where people have adapted to hotter summers through both widespread use of air conditioning and physical acclimatization. Regardless, heat-related deaths can be especially high wherever large numbers of elderly people reside.[14]

Air conditioning may be an important tool in coping with extreme heat but it is not a simple fix given the dangerous brownouts and blackouts created by peak electricity demand in summer, which could increase along with rising temperatures. A recent study of electricity demand in New York City and its surrounding counties under different climate projections found that peak demand on a 101°F day with 80 percent humidity would be nearly 40 percent higher than on an 85°F day with 40 percent humidity.[16]

An effective system for protecting public health that combines heat warnings with outreach directed at the most vulnerable urban dwellers has already been implemented in more than two dozen cities around the world.[17] Philadelphia, once known in some circles as the "Heat-Death Capital of the World,"[18] was the first to adopt such a system (starting in 1995). The city focuses its efforts on the elderly, homeless, poor, and other socially isolated populations; during a heat alert, health-department staff visit elderly residents in their homes and reach out to the homeless; electric utilities are barred from shutting off services for non-payment; and senior-citizen centers and other public places with designated spaces for cooling off extend their hours. The plan has proven to be a cost-effective means for saving lives.[19]

Adoption of similar public-health programs could help other cities in the Northeast reduce the adverse health effects of extreme heat, but such adaptation measures cannot eliminate the threats posed by the most severe climate changes (as projected under the higher-emissions scenario). Although recent emissions guarantee some increase in heat waves, swift action to reduce emissions can help the region avoid even more dangerous, and potentially deadly, heat.

Health Effects of Extreme Heat

Heat stress, heat exhaustion, and life-threatening heat stroke can occur as the human body tries to cool itself during prolonged periods of extreme heat. The body first increases blood flow to the skin, thereby reducing the flow to muscles, the brain, and other organs, which can cause fatigue and light-headedness. If intense heat continues, the body begins drawing water from the bloodstream to form sweat, which cools the body as it evaporates from the skin. If a person does not drink enough fluids while sweating, blood volume declines until the body is no longer able to cool itself, which can eventually cause brain damage and death. Those most at risk from extreme and unrelenting heat include the elderly, the poor, young children, and people who already suffer from certain illnesses (particularly heart disease).[15]

AIR QUALITY

Air pollution from ground-level ozone and fine particulate matter (such as soot)—primary components of smog—is already a serious concern throughout most of the Northeast. In 2004, for example, the U.S. Environmental Protection Agency (EPA) found at least part of every state in the region except Vermont to be out of compliance with its ground-level ozone standards (which limit average ozone concentrations to 0.08 part per million over an eight-hour period). Since then, the Northeast's states have been working to improve their air quality and, by the end of 2006, ozone concentrations in Maine had improved enough to meet the EPA standard.[20,21] However, the region still hosts five of the nation's 25 most ozone-polluted metropolitan areas:[22]

- New York City-Newark-Bridgeport (encompassing counties in Connecticut, New Jersey, New York, and Pennsylvania; #9 overall)
- Philadelphia-Camden-Vineland (encompassing counties in Delaware, Maryland, New Jersey, and Pennsylvania; #10 overall)
- Pittsburgh-New Castle (Pennsylvania; #17 overall)
- Youngstown-Warren-East Liverpool (encompassing counties in Ohio and Pennsylvania; #20 overall)
- Buffalo-Niagara-Cattaraugus (New York; #5 overall)

Reduced air quality is already putting large numbers of people in the region at risk from respiratory ailments such as asthma, chronic bronchitis, and emphysema.[23] On days when ozone and/or fine particulate-matter concentrations are elevated, both children and adults are more likely to have difficulty breathing, and people with asthma may require a visit to the emergency room. High humidity levels and temperatures (i.e., high heat-index values) exacerbate the effects of poor air quality.

Ozone concentrations are determined by a number of factors including local meteorological conditions, local vehicle and industrial emissions of

Smog Blankets Philadelphia

As the country's tenth most ozone-polluted metropolitan area, Philadelphia is sadly accustomed to smog—a potent combination of ground-level ozone and fine particulate matter (such as soot). Such conditions are projected to become more commonplace, particularly under the higher-emissions scenario, unless local vehicle and industrial emissions of ozone-forming pollutants are greatly reduced.

An Increasingly Common Sight in the Northeast?

Poor air quality puts large numbers of people in the region at risk from respiratory ailments such as asthma, chronic bronchitis, and emphysema. Today, one in four children in Harlem suffers from asthma.[24] On days with poor air quality, which could increase due to global warming, both children and adults are more likely to have difficulty breathing, and people with asthma may require a visit to the emergency room, where this Harlem mother and her child find themselves.

ozone-forming pollutants (or "precursors") such as nitrogen oxides (NOx) and volatile organic compounds, and pollution blown in from out of state. Summer weather is especially conducive to high ozone levels.[25]

Several recent studies indicate that temperature increases and other climate changes are likely to exacerbate air-pollution problems and make it more difficult for Northeast cities to meet regulatory standards by:[26,27,28]

- Accelerating ozone-forming chemical reactions in the atmosphere
- Increasing the frequency and duration of air stagnation, which allows pollution to accumulate
- Increasing the emissions of natural ozone precursors (volatile organic compounds) from plants

Some climate models also project reductions in summer cloudiness, which would further accelerate chemical reactions by increasing solar radiation.[29]

Through these mechanisms, global warming is expected to worsen air quality in the region and counteract the positive effects of lower emissions of nitrogen oxides and other ozone precursors that might be gained through stringent regulation. This means that under future climate conditions, policies designed to improve the Northeast's air quality will require even greater reductions of ozone precursors than would be needed today to achieve the same result. One recent study, for example, found that warming in the Midwest through mid-century is projected to require a 25 percent greater reduction in NOx emissions than would be needed today to achieve the same improvements in air quality.[30]

Projected changes in ozone levels

A combination of global and regional models can be used to project the impacts of global warming on the Northeast's air quality.[31,32,33] The projections used in this assessment focus only on the effects of changes in climate and assume that regional releases of ozone precursors remain fixed at present-day levels.[34]

Under these conditions, the number and duration of episodes in which ozone exceeds federal regulatory standards (in terms of mean summer daily and eight-hour maximum ozone concentrations) are projected to increase, particularly under the higher-emissions scenario used in this study. By the end of this century, unless local vehicle and industrial emissions of ozone-forming pollutants are substantially reduced:

- The number of days when the EPA's eight-hour ozone standard is exceeded in the Northeast is projected to increase by more than 300 percent under the higher-emissions scenario, compared with a 50 percent increase under the lower-emissions scenario.
- Both mean daily and eight-hour maximum

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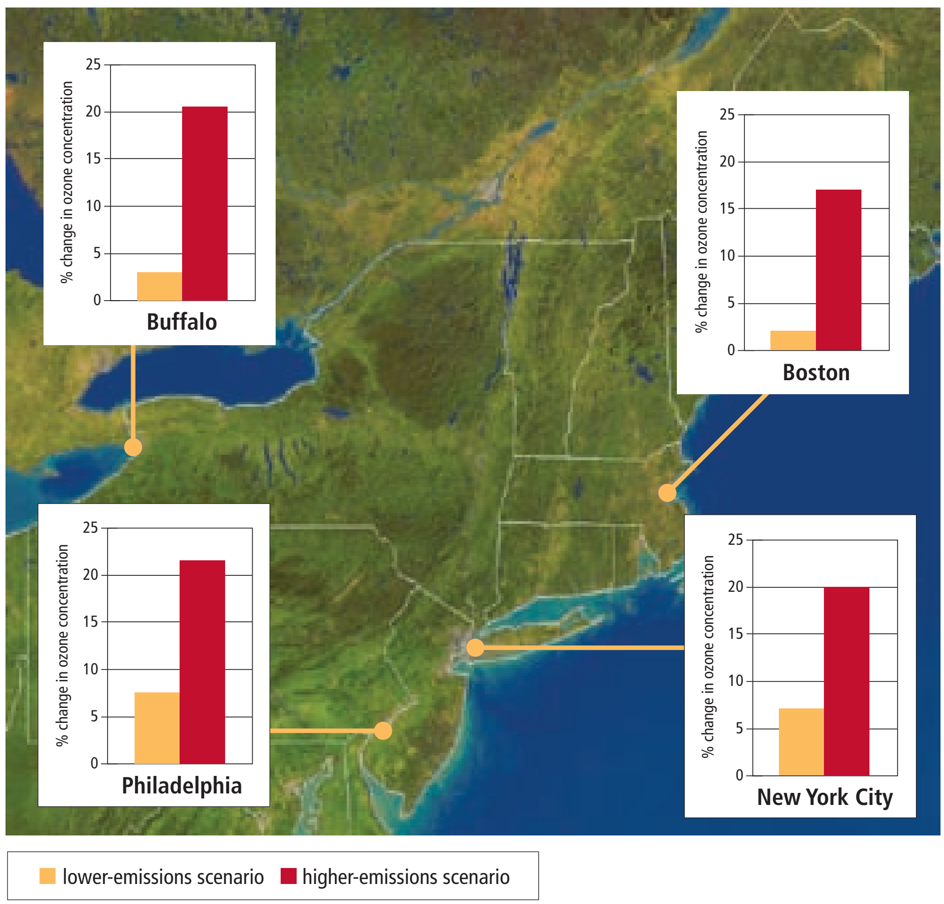
FIGURE 13: Increasing Risk of Poor Air Quality in Northeast Cities



Hotter summers could set the stage for an increase in the number of days that fail to meet federal air-quality standards. In the absence of more stringent controls on ozone-forming pollutants, the number of days with poor air quality is projected to quadruple in Boston, Buffalo, New York City, and Philadelphia under the higher-emissions scenario. Under the lower-emissions scenario such days could increase by half. These graphs show the average projected change in eight-hour maximum ozone concentrations for each city.

Allergies and Asthma on the Rise

From the sniffling and sneezing of seasonal hay fever to life-threatening asthma attacks, allergy-related diseases rank among both the most common and the most costly chronic illnesses affecting the U.S. population. Nearly 40 million people suffer from hay fever, which causes an estimated 4 million lost days of work and school each year;[35] asthma afflicts about 25 million Americans, including 9 million children and 16 million adults.[36]

Nearly 1 in 10 people in Connecticut, Maine, Massachusetts, New Hampshire, and Rhode Island suffer from asthma—a higher rate than the national average of 1 in 12.[37] Asthma is the most common chronic disease among children, and poor inner-city children are most at risk; a 2003 study diagnosed asthma in a startling one-quarter of the children in New York City's central Harlem district.[38]

While the causes of allergic diseases are complex—asthma is believed to require both a genetic predisposition and exposure to certain conditions during early childhood—we do know that indoor and outdoor air pollutants can trigger attacks and may even promote the development of these diseases.[39] Rising temperatures and changing precipitation patterns associated with global warming are expected to alter the amounts and timing of airborne allergens such as pollen grains and perhaps fungal spores, which in turn could exacerbate allergy symptoms and possibly the incidence of allergic diseases across the Northeast.[40]

Pollen grains from different plant sources give rise to three distinct hay fever seasons in the Northeast: tree pollen in spring, grass pollen in summer, and ragweed pollen in fall. Traits such as growth rates, bloom times, pollen production, and geographic distribution in all of these plant types can be altered by both higher air temperatures and atmospheric CO_2 levels (which are responsible for much of the warming).

Effects of temperature and CO_2

Rising temperatures are expected to trigger an earlier onset of the spring allergy season and could lead to higher pollen-production rates in some plants. In Europe, for example, warming trends over the past 35 years have been linked with earlier spring flowering and pollen release in birch trees, a known source of allergenic pollen.[41] Likewise, western ragweed responds to simulated increases in summer temperatures with accelerated growth and an 85 percent boost in pollen production.[42] As temperatures in the Northeast continue to rise and spring arrives ever earlier, a number of other weed species are likely to experience increased growth and pollen production as well.[43]

Rising CO_2 levels in the atmosphere not only worsen allergies indirectly by driving temperatures higher but also directly by increasing many plants' flowering and pollen-production rates. Experiments have indicated that CO_2-enriched air can increase

Late Spring Pollen Coats a River

Warmer temperatures and higher CO_2 levels are expected to increase production of pollen allergens.

Increased Temperature and CO_2 Levels Drive Greater Pollen Production

Plants such as ragweed (pictured here) are projected to increase production of pollen, likely translating into more—and more severe—asthma and other allergy-related disease in the Northeast. In some urban areas, nearly one in three children suffer from asthma or asthma-like symptoms,[53] and across Maine, New Hampshire, Massachusetts, Connecticut, and Rhode Island nearly 1 in 10 adults has been diagnosed with asthma.

the allergenic potential of poison ivy[44] and allergenic-pollen producers such as ragweed and pine trees.[45,46] Loblolly pines, for example, produce pollen at a younger age and in greater quantities in CO_2-enriched air.[47] Similar findings for common ragweed suggest that this weed may not only be germinating earlier due to recent warming, but also producing more flowers and pollen in response to increasing CO_2 levels.[48,49,50]

Indeed, ragweed that already grows in the Northeast's heavily urbanized areas may be a harbinger of what lies ahead for the region's allergy sufferers. In Baltimore, where CO_2 levels are approximately 25 percent higher than in the surrounding countryside (511 versus 389 parts per million) due to higher levels of car exhaust and industrial emissions, and temperatures are higher due to the urban heat-island effect, ragweed flowers significantly earlier and produces more pollen than ragweed growing in nearby rural and semi-rural areas.[51]

Generally speaking, urban CO_2 levels in the Northeast are already 15 to 25 percent higher than rural levels. Under the higher-emissions scenario these present-day urban CO_2 levels would be expected across the entire region within the next several decades. By the end of the century CO_2 levels would climb to more than double their present-day urban levels. Under the lower-emissions scenario CO_2 levels would also reach present-day urban levels, although not until mid-century or later.

Pollen production in the Northeast's urban centers would likely continue to rise but at a gradually declining rate, eventually reaching a saturation point where no further increase would be observed.[52] Thus, in just the next several decades, continued high emissions could drive a significant boost in pollen-based allergies.

As both temperatures and ambient CO_2 levels rise, increases would be expected across the Northeast in both the production of pollen grains and, potentially, the allergenic potency of individual pollen grains. This in turn may exacerbate wind-borne, plant-based allergies across the region and increase exposure to pollen associated with respiratory problems. Combined with other global warming-influenced factors such as air pollution, an increase in airborne allergens would likely translate into an increase in the incidence and severity of asthma and other allergic diseases in the Northeast.

ground-level ozone concentrations are projected to increase 10 to 25 percent under the higher-emissions scenario and 0 to 10 percent under the lower-emissions scenario.

- In Boston, eight-hour maximum ground-level ozone concentrations are projected to increase 13 to 21 percent under the higher-emissions scenario and 0 to 5 percent under the lower-emissions scenario.
- In Buffalo, ozone concentrations are projected to increase 12 to 29 percent under the higher-emissions scenario and 0 to 8 percent under the lower-emissions scenario.
- In New York City, ozone concentrations are projected to increase 15 to 25 percent under the higher-emissions scenario and 3 to 11 percent under the lower-emissions scenario.
- In Philadelphia, ozone concentrations are projected to increase 17 to 26 percent under the higher-emissions scenario and 4 to 11 percent under the lower-emissions scenario.

Of course, climate change is not the only factor complicating current efforts to improve air quality in the Northeast. Clearly, stringent policies designed to reduce emissions of NOx and other ozone precursors can be implemented to avoid the large increases in ozone described above. Improving the region's air quality will therefore require concerted efforts to reduce regional releases of ozone precursors as well as the regional and global heat-trapping emissions that drive climate change.

VECTOR-BORNE DISEASE

Compared with extreme heat, vector-borne diseases cause relatively few deaths in the Northeast, yet they tend to attract a great deal of media attention and public concern. A number of high-profile infectious diseases in the region are transmitted between animal and human populations by means of blood-feeding disease-carriers or "vectors." Mosquitoes, ticks, and other vectors carry disease-causing bacteria and viruses and spread them to the animals or people they bite (without suffering illness themselves). Global warming is likely to affect both the incidence of such diseases already endemic to the region and the introduction of new diseases. However, the complex interactions involved in spreading these diseases make specific projections difficult.

Many vector populations, for instance, are extremely weather-sensitive. For some, expansion into many northern areas of the continental United States is currently limited by cold temperatures. As temperatures rise, vectors carrying encephalitis viruses or malaria parasites may be able to spread into these areas.[54,55] Consider the role of one key vector: the mosquito. Warm summer conditions tend to stimulate mosquito breeding and biting,[56] and summers are projected to arrive earlier in spring and extend later into the fall, lengthening the mosquito season. This could increase the risk of mosquito-borne diseases such as West Nile virus (WNV), but it must be noted that the risk of transmission depends not only on temperature but also on the frequency of extreme weather-related events such as seasonal droughts and heavy rainfall—both of which are projected to increase, particularly under the higher-emissions scenario (see below).

In addition to climate change, the spread of vector-borne diseases often involves land-use changes that create favorable habitats for various animals that host a disease, the vectors that transmit it to humans, or the disease-causing microorganisms themselves. All of these organisms will be affected both directly and indirectly by climate change, making it difficult to quantify all of the potential changes

Projected Northeast Climate Could Set Stage for WNV Outbreaks

Climate projections point toward future conditions (warmer winters, hotter summers, more frequent dry periods punctuated by heavy rainstorms) that can set the stage for more frequent human outbreaks of diseases such as the mosquito-borne West Nile virus (WNV), particularly under the higher-emissions scenario. WNV is often transmitted to humans by the *Culex pipiens* mosquito (shown here). Current responses to this threat include aerial pesticide spraying.

in vector-borne disease risk that may be related to global warming.

West Nile virus

The first U.S. outbreak of WNV occurred in New York City in 1999, as the city experienced its driest and hottest spring and summer in a century, followed by drought-ending downpours.[57,58,59] Within five years, the disease had spread west across North America, transmitted by mosquitoes that acquire the virus from infected birds.

WNV causes no symptoms in 80 percent of the infected human population, with most of the rest experiencing only mild flu-like symptoms. One in 150 infected people, however, develop serious illnesses including the brain inflammation known as encephalitis. In 2005, 76 cases of WNV and eight deaths were reported in the Northeast; 3,000 cases and 119 deaths were reported nationwide. West Nile-related health-care costs were estimated at $200 million in 2002.[60]

In Africa, Europe, Russia, and the Middle East—where the U.S. WNV strain originated—outbreaks in humans are associated with extreme heat and drought, often followed by severe rainstorms. Drought has recently emerged as a common feature of outbreaks in the United States as well.[61,62,63,64] During a drought, birds migrate to wetter areas and the mosquitoes that normally prey on birds switch to humans.

WNV outbreaks also occur regularly in desert regions where mosquitoes tend to concentrate in wetter, human-occupied areas such as irrigated fields and lawns, roadside ditches, and pools. The hotter the temperature, the higher the probability that a mosquito will transmit the virus when it bites because heat increases the amount of virus it carries.[65]

Climate projections used in the NECIA analyses show a trend toward warmer winters in the Northeast followed by hotter summers, which will likely feature more frequent dry periods punctuated by heavy rainstorms that increase the risk of flooding. These are the same conditions that can set the stage for more frequent WNV outbreaks.[66,67,68] With the exception of heavy rainstorms, which are projected to increase in frequency under either emissions scenario, each of these climate changes is projected to be more pronounced under the higher-emissions scenario than under the lower-emissions scenario. Understanding the conditions that signal an increasing risk of outbreaks should allow communities in the Northeast to prepare public-health measures that will be more effective in reducing the risk.

Lyme disease

This bacterial infection transmitted by ticks has become the most common vector-borne disease in the United States. Although cases have been reported in all 50 states, the Northeast accounts for 90 percent of the more than 100,000 cases reported nationwide since 1982.[69] Because tick populations flourish after mild, wet winters, it has been suggested that increased winter temperatures and precipitation could facilitate the spread of Lyme disease.

On the other hand, ticks prefer cooler temperatures in summer, so the projected summer warming in the Northeast could reduce tick populations and disease risk.[70] This, along with a combination of ecological and human factors, makes it difficult to predict the net change in Lyme disease risk.[71]

Global movements of diseases, vectors, and host species will be driven by changes in climate, land use (as in the case of urban sprawl), and even inadvertent transport (e.g., WNV was likely transported to New York City from the Middle East on an airplane carrying an infected mosquito, person, or pet bird). In terms of land use, vectors such as ticks, mosquitoes, and black flies tend to concentrate in the transition zones where roads, housing, and other human developments encroach on natural ecosystems, bringing people into greater contact with diseases that were once confined to wildlife.[72] For example, the encroachment of suburban homes into former woodlands is linked with increased Lyme disease risk.[73]

Human activities will therefore tend to exacerbate the impacts of global warming on vector-borne disease in the Northeast. Lastly, research suggests that rapid genetic mutation has allowed certain mosquito species to adapt to recent climate changes in the Northeast (for example, mosquitoes are already better suited to the longer frost-free season in Maine's North Woods).[74]

Social Vulnerability and Climate Change in the Northeast's Cities

People everywhere will be affected by global warming. Their vulnerability stems both from their location and exposure to climate-related risks—e.g., those situated in a floodplain—as well as from a range of social, economic, and demographic factors.[75]

The experience of Hurricane Katrina in August 2005 offered a stark illustration of how these factors can come into play during climate-related disasters,[76] and the call to political leaders to address the root causes of social vulnerability still reverberates. The Northeast, home to more than 49 million residents, faces a growing income gap between rich and poor (and other social inequalities).[77] These conditions can affect the way in which individuals, families, and communities in the region respond to extreme weather such as heat waves, nor'easters, and summer droughts (which are projected to increase in intensity and frequency due to climate change).

A person's or community's vulnerability to weather-related hazards is the result of three interacting factors: *exposure* to risk (for example, living along the flood-prone shore versus on higher ground, or in older housing versus newer construction), *sensitivity* to the risk (for example, due to being older or in poor health), and the *ability to cope with and recover from* the event (for example, as a result of financial well-being, literacy, political representation, and access to transportation, communication, electricity, and other resources).[78,79] In general, a lack of material resources and social networks translates into high vulnerability.[80,81]

New research conducted for this analysis used neighborhood-level socioeconomic indicators to identify socially vulnerable populations and locales within the Northeast. This can help policy makers determine which groups and areas need the most assistance in coping with or adapting to a variety of climate-related hazards.

The unique vulnerability of cities

Weather and climate in the Northeast do not affect all parts of the region equally. While large cities often possess substantial assets for coping with and adapting to climate change (e.g., responsive municipal governments, vocal watchdog and advocacy organizations, significant financial resources or access to state/federal resources), their existing physical and socioeconomic infrastructure often increases exposure to climate and weather risks. Highly urbanized areas are particularly vulnerable to extreme heat, for instance, while intensively developed communities along the coast and in floodplains bear an elevated risk of flood damage.

Moreover, densely populated and built-up areas also tend to experience greater heat exposure. During back-to-back summer heat waves in 2006, for example, the New York City metropolitan area was much hotter at night than many surrounding communities. On one typical night, LaGuardia Airport in Queens registered 87˚F at 10 p.m. while, just an hour's drive away, it was a comfortable 72˚F in rural Port Jervis, NY; this pattern persisted for days.

Why did the city not cool off at night? In big cities the high concentration of heat-absorbing materials (such as concrete, pavement, and brick) and constantly active machinery that emits exhaust heat (such as cars, trains, and air conditioners) causes air temperatures to be considerably higher than in more open, rural settings dotted with fields and forests. This condition, called the urban heat-island effect, traps heat over the course of a day and slowly releases it after the sun goes down.

The resulting extremely hot conditions are particularly challenging at night, when people need relief from high temperatures to maintain their health. When this relief does not come, the risk of heat stress, respiratory illness, and other ailments increases. In Boston, Hartford, New York, and Philadelphia elevated heat-stress mortality rates are seen in certain lower-income and immigrant neighborhoods, suggesting that these communities are more socially vulnerable to heat than others.[82] Climate projections show that extreme heat and heat stress will likely increase in the Northeast's cities. (See the text box on the health effects of extreme heat.)

How can people cope with the looming health hazard posed by rising temperatures? Increased air conditioning on its own is not a solution, given the associated costs, risks, and further contribution to global warming. (See the section on extreme heat.)

Urban Residents on the Front Line of Extreme Heat

Neighborhoods in the Northeast's cities facing the greatest risk from climate change (e.g., increases in extreme heat) are typically characterized by factors such as a high percentage of elderly people and people living in isolation, limited social networks, and a high prevalence of existing health problems (e.g., chronic illnesses such as asthma). More than 80 percent of New York City residents who died as a result of the heat wave that struck in 2006 were age 50 or older.

In contrast, early warning systems, communal spaces for cooling off, and improved access to emergency care (especially for the less affluent) are all elements of an effective system for coping with extreme heat. NECIA analyses found that neighborhoods in the urban centers of older cities in the Northeast are highly vulnerable to climate-related hazards including extreme heat.[83] These neighborhoods also face a multitude of socioeconomic challenges such as poverty, unemployment, and lack of access to quality education, which are closely related to other factors that directly determine vulnerability to climate change. And, because these neighborhoods make up a small percentage of their metropolitan area's total population, they can suffer from poor political representation. Public-policy solutions to these problems will help lower these communities' vulnerability to hazardous climate conditions.

Strategies for reducing social vulnerability in urban areas

Reducing social vulnerability requires addressing its three underlying factors. Reducing people's *exposure* to climate-related risks can be addressed, for example, through raising awareness of heat- or flood-related risks, evacuating people from floodplains, preventing development in hazardous areas when possible, and providing access to spaces for cooling off during prolonged periods of extreme heat. Focusing on populations and communities that are particularly vulnerable to climate-related hazards, such as the elderly during heat waves, would address *sensitivity* to risk. Finally, to enhance people's *ability to cope with and recover from* a climate-related hazard, a wide variety of measures are necessary, ranging from the immediate aid provided during and after disasters to deeper societal changes that enable and empower people to live safe and productive lives. Examples may include greater access to health or flood insurance, improving employment and income levels, improving literacy and educational achievement, expanding access to transportation and communication, and fostering social networks so isolated individuals will not be forgotten or left behind during emergencies.

Implementation of such measures needs to be planned for and begun well before an emergency arrives. Lowering exposure to extreme heat, for example, can mean increasing the amounts of green space and tree cover in cities, which reduce the urban heat-island effect. New Jersey has planted thousands of trees in its major cities, and New York City's borough of the Bronx has developed a similar initiative. Cities across the Northeast can also make affordable energy-saving technologies and building supplies available to low- and moderate-income apartment dwellers and homeowners. Finally, "green" building and infrastructure standards can produce buildings and sidewalks that stay cooler, use less energy, and produce less exhaust heat. (See the Meeting the Climate Challenge chapter.) Implementing measures that reduce sensitivity or increase people's ability to cope and recover may take even longer lead times.

CHAPTER EIGHT

Meeting the Climate Challenge in the U.S. Northeast

KEY FINDINGS

- **Continued heavy reliance on fossil fuels will keep the world on a higher-emissions pathway, such as the scenario used in this assessment, and risk severe consequences for the Northeast's economy and well-being.**
- **Concerted action to reduce emissions in the Northeast—on the order of 80 percent below 2000 levels by mid-century and just over 3 percent per year on average over the next few decades—can help pull global emissions below the lower-emissions scenario described here. As both a world leader in technology, finance, and innovation and a major source of heat-trapping emissions, the Northeast is well positioned to help drive national and international progress toward this goal.**
- **The Northeast's decision makers—from individual households to industry and government—have myriad options available today for reducing emissions from each of the region's four major sources of CO_2: electric power, buildings, transportation, and industry.**
- **Consumers and policy makers at all levels can accelerate the region's transition from fossil fuels to clean, renewable energy resources (including solar, wind, and geothermal) through energy choices supported by market incentives and regulations.**
- **Energy users can significantly curb emissions by embracing efficiency: purchasing energy-efficient lighting and small appliances and replacing vehicles, heating and cooling systems, motors, and large appliances with more efficient models at the end of the existing equipment's useful lifetime.**
- **States and cities can use zoning laws, building codes, and incentives to encourage energy-efficient buildings, discourage sprawl, and provide low-emissions transportation alternatives.**
- **Because past emissions have committed the region and the world to some unavoidable level of global warming over the next several decades, decision makers in the Northeast must help vulnerable constituencies adapt to the consequences. Informed policies and actions can reduce exposure to climate risks (such as catastrophic flooding) and increase the ability of vulnerable sectors and communities to cope with climate change and recover after extreme events or disasters.**
- **For each adaptation measure considered, policy makers and resource managers must carefully assess the potential barriers, costs, and unintended social and environmental consequences.**
- **These strategies for confronting climate change in the Northeast can also advance other widely shared regional goals such as enhancing energy security, creating jobs, producing cleaner air, and building a more sustainable economy. The costs of delay are high—the time to act is now.**

INTRODUCTION

Global warming is already affecting the economy, lifestyles, and traditions of the Northeast, and the impacts of a changing climate will grow more substantial in the decades to come. At least some further climate change is unavoidable and, as highlighted in this report, the expected impacts on our region include increased summer heat waves, poorer urban air quality, reduced winter snow cover, northward shifts in the range of species (including trees, fish, and agricultural crops), and increased coastal flooding and erosion. However, the extent of future warming—and the severity of the changes to which our region must adapt—will depend largely on energy and land-use choices made within the next few decades, both in the Northeast and worldwide.

NECIA analyses have projected many striking differences in the extent of impacts, depending on whether the world follows a higher- or lower-emissions pathway. For example, based on the emissions pathways used in this assessment, that choice is projected to determine over the course of this century whether:

- the residents of Philadelphia endure almost a month's worth of summer days over 100°F, or just over one week of such days;
- each year, New York City has a 1 in 10 or 1 in 20 probability of experiencing coastal flooding equivalent to today's 100-year flood;
- the storied fishing grounds of Georges Bank continue to support cod;
- a reliable ski season can be expected in only western Maine, or in other northern parts of the region; and
- heat-stress related reductions in milk production will be 5 to 20 percent or 5 to 10 percent—unless Pennsylvania dairy farmers can afford cooling options.

In many cases, the impacts of warming in the Northeast will be considerable even if the world follows the lower-emissions scenario used in this report.

- Boston and Atlantic City, NJ, are projected to experience coastal flooding equivalent to today's 100-year flood almost every year on average by the end of the century.
- The snowmobile season is projected to be marginal or non-existent across most of the region by mid-century.
- Many of the region's cities, including Buffalo, Hartford, and Concord, NH, are expected to experience three times as many days of extreme heat by late-century as they do now.
- Lobster (which may become more productive in northern waters) is expected to disappear from Long Island Sound and the nearshore waters off Rhode Island and south of Cape Cod.
- Habitat suitable for spruce/fir forests—a primary source of sawlogs and pulpwood as well as a favored recreation destination—is projected to all but disappear from the region.

The higher-emissions scenario described in this report does not represent a ceiling for the changes the world and the Northeast may experience. Yet neither does the lower-emissions scenario represent a floor. The lower-emissions scenario describes a world in which atmospheric concentrations of CO_2 rise from approximately 380 parts per million (ppm) today to approximately 550 ppm by the end of the century—in contrast to 940 ppm under the higher-emissions scenario. However, many lines of evidence indicate that even lower emissions—and thus less severe impacts—are well within our reach.

The latest IPCC assessment describes the technical and economic potential for stabilizing atmospheric concentrations of heat-trapping gases at or below the CO_2 equivalent of 450 ppm.[1,2] Recent analyses indicate that achieving such a target would require the United States and other industrialized nations to reduce emissions some 80 percent below 2000 levels by mid-century, along with substantial reductions by developing countries.[3,4]

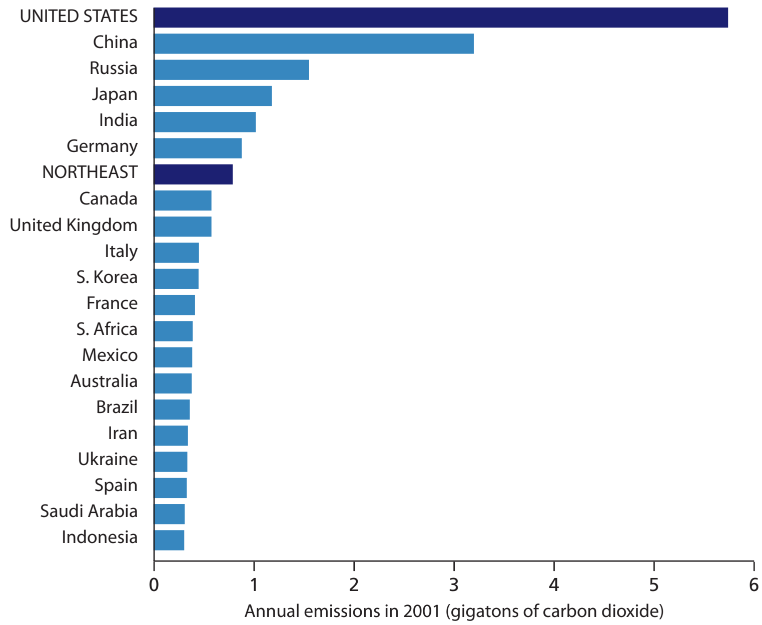
In the Northeast, as well as elsewhere in the United States and internationally,[5] there is growing momentum to pursue these deep reductions. In 2001, New England governors and Eastern Canadian premiers signed an agreement committing their states and provinces to a comprehensive Climate Change Action Plan that includes a long-term goal of reducing regional emissions 75 to 85 percent below then-current levels. More recently, policy makers in California and New Jersey have set ambitious near- and longer-term targets for reducing emissions, and similar measures are being debated in statehouses across the country and in Congress.[6]

Even if future emissions can be dramatically curtailed, however, past emissions guarantee that the Northeast and the world will experience at least some additional warming and significant impacts over the next several decades. Policy makers and communities across the Northeast must, therefore, begin adapting to the unavoidable consequences of this warming.

Mitigation (in the form of emissions reductions) and adaptation are essential and complementary strategies for addressing global warming. Aggressive steps to reduce emissions can limit the scope and costs of regional impacts and thus increase the prospect that ecosystems and societies will find effective ways to cope with climate change and take advantage of any potential benefits. In turn, timely and effective adaptation will help reduce the vulnerability of societies and ecosystems to further warming.

Sector-specific options and opportunities for adaptation were discussed earlier in this report. The section on adaptation in this chapter provides broader cross-cutting lessons and principles for dealing with the unavoidable impacts of global warming in the Northeast.

FIGURE 14: Northeast U.S. Emissions: Significant on a Global Scale



Energy-related carbon dioxide emissions in the Northeast, compared with the major carbon-emitting nations of the world. U.S. emissions include the Northeast.

Source: Emissions data for 2001 from Energy Information Administration (EIA), *International energy annual* (2003), and EIA, *Emissions of greenhouse gases in the United States* (2004).

REDUCING EMISSIONS IN THE NORTHEAST

Reducing emissions in the Northeast alone will not stem global warming; nevertheless, the region can play a significant role in responding to this global challenge. Taken together, the Northeast's nine states ranked as the world's seventh highest emitter of CO_2 compared with entire nations in 2001, just behind India and Germany and ahead of Canada.[7]

However, the Northeast is also a financial and intellectual powerhouse, a world leader in science and technology, and a historic innovator in public policy. Even with its growing economy and population, the region has managed to slow its growth in energy-related CO_2 emissions to just 0.3 percent per year since 1990—well below the national average of 1 percent per year—through a combination of past energy and transportation policies, expansion of less energy-intensive industries such as biotechnology, and other factors.

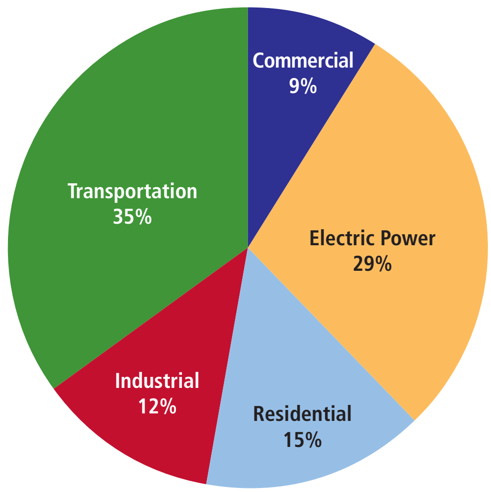
Today, the Northeast is well positioned to help lead the national and international actions needed to ensure a healthy future climate for our children and grandchildren—and to reap the economic benefits of leading-edge entrepreneurship. Recent examples of the region's leadership and innovation in reducing heat-trapping emissions include:

- The Regional Greenhouse Gas Initiative (RGGI), the first U.S. multi-state cap on carbon emissions, which will require the electric-power sector to decrease its emissions 10 percent below current levels by 2019. (See the related text box.)
- Many state-level actions (including policies to promote energy efficiency and renewable energy, clean cars, and climate action plans) and efforts to reduce emissions from state government activities.
- Emissions-reduction strategies being implemented by many municipalities, corporations, and universities.

These are important first steps upon which to build. Starting now and continuing over the next several decades, decision makers in federal, state, and local governments, the business sector, public institutions, and individual households can choose from among many proven or promising strategies that can rapidly put the region on the path to deep emissions reductions. (See the Citizen's Guide text box.) The specific policies, programs, and practices outlined below for each of the region's four major CO_2-emitting sectors (electric power, buildings, transportation, and industry) approach the problem from every available point of leverage—ranging from market forces to regulation—that can help move the Northeast toward a low-emissions, high-efficiency future.

This report proposes an achievable goal of

FIGURE 15: Northeast States—Regional Emissions of CO_2 by Sector, 2003



Source: State Energy Data System. Table 2, 2003 State Emissions by Sector.

emissions reductions on the order of 3 percent annually over the next several decades. (See the text box on the "3 percent solution.") Many of the solutions outlined here would achieve even greater emissions reductions—as well as cost savings—for those who adopt them.[8]

REDUCING EMISSIONS BY SECTOR

The transportation sector is the Northeast's largest source of heat-trapping emissions, followed by electricity generation (Figure 15). Together, these sectors account for nearly two-thirds of the region's emissions. Combustion of fossil fuels for water and space heating in homes and businesses and for powering industrial activities accounts for the remaining third.

Electric power

Electricity generation in the Northeast relies substantially on fossil fuels, a circumstance that provides a host of near-term opportunities to reduce emissions. The region's aging fleet of inefficient coal- and oil-burning power plants could be steadily replaced over the next decade under the pressure of new market-based policies that attach a price to carbon emissions and make cleaner, more efficient generation and low- or zero-emissions technologies financially attractive. (See the text box on RGGI.) Successful implementation and expansion of policies and programs that place energy-efficiency gains on an equal footing with new power generation can support this shift.

Managing demand for electricity

Many of the most cost-effective opportunities to reduce emissions from the electric-power sector lie in reducing demand. Numerous technologies are available today that decrease the amount of energy required to provide services such as lighting, refrigeration, heating, and air conditioning, and to operate appliances, pumps, fans, and industrial motors; these technologies can reduce household and business energy bills while reducing emissions. A recent analysis found that cost-effective investment in energy efficiency throughout the New England states could offset more than eight years' worth of projected growth in electricity demand.[9]

Despite this potential, cost-effective opportunities are missed every day due to a host of well-understood but difficult-to-overcome market barriers, including a lack of information about efficient technology options, a persistent focus on the up-front costs rather than long-term operating and maintenance costs, and incentives that are split between building owners and tenants (and fail to provide either with incentives for investing in efficiency). Expanded government- and utility-run efficiency programs could help overcome these market barriers and deliver more cost-effective reductions in energy demand.[10]

Power-generation efficiency can also be greatly

SUCCESS STORY

New Jersey's statewide Clean Energy program, coordinated by the New Jersey Board of Public Utilities, offers all residential, commercial, and industrial utility customers, as well as municipalities, extensive programs for making energy-efficiency improvements and installing or purchasing renewable energy. In addition, programs targeted to home builders and commercial developers are designed to maximize efficiency gains and incorporate renewable energy technologies in new construction. These programs have delivered substantial energy savings.[11]

The 3 Percent Solution

How can we put the Northeast on a path that will reduce emissions on the order of 80 percent below 2000 levels by mid-century? Concerted, sustained effort to reduce emissions by just over 3 percent per year on average would achieve nearly half of the total reductions needed by 2030,[12] putting the region well on track for achieving the 80 percent mid-century goal.

Some immediate first steps that individuals, companies, communities, and states can take without waiting for policy changes include:

- Adopting energy-conservation practices and upgrading small-scale technology such as lighting and small appliances with more energy-efficient models.
- Committing to "efficient replacement" strategies that significantly increase the efficiency of technologies at the end of their useful lifetimes. The energy savings from more efficient vehicles, major home and commercial appliances, heating/ventilation/air conditioning (HVAC) systems, and industrial motors and pumps will, in general, more than make up for higher up-front costs.
- Improving the energy performance of homes and workplaces by improving insulation, reducing air leaks, and installing more advanced lighting and HVAC control systems.
- Voluntarily purchasing low- and zero-emissions electricity.
- Purchasing "carbon offsets" (i.e., investing in carbon-storing forests or renewable energy projects in order to offset carbon emissions that are currently difficult to avoid, such as those related to air travel).[13]
- Supporting political leaders who champion policies that will put productive, cost-effective solutions in place sooner rather than later.

Making the 3 percent solution work is like putting a puzzle together. Individuals in households, businesses, institutions, and governments each control pieces of the puzzle and can contribute to steady annual reductions. Reliance on individual actions alone will not achieve the transition to a low-carbon economy, but individual actions are needed to demonstrate the feasibility of new approaches as well as their economic, air-quality, and energy-security benefits.

In addition to taking actions that will reduce emissions directly, any individual, institution, or company can support the development of strong local, state, and national policies for reducing emissions. A combination of policies that provide incentives while setting strict emissions standards for power plants, buildings, industry, transportation, and other CO_2 sources is essential.

improved, especially by incorporating technology that uses so-called waste heat from commercial and industrial facilities to generate electricity in small combined-heat-and-power (CHP) plants. CHP facilities can use a wide range of fuels including biomass, but most are fueled with natural gas. Compared with the typical efficiency of about 30 percent for older fossil fuel-fired plants and about 50 percent for advanced natural gas combined-cycle plants, CHP systems[14] can utilize more than 80 percent of the fuel's energy content, thereby greatly reducing emissions compared with traditional facilities.[15,16]

Renewable energy

Renewable energy resources including solar, wind, geothermal, tidal, and biomass energy offer increasingly cost-effective opportunities to replace fossil fuels and produce electricity with virtually no global warming emissions. Over the past 20 years the performance and cost-effectiveness of these technologies have improved dramatically.

Wind energy represents one of the most attractive near-term prospects among renewable resources for making substantial, relatively low-cost contributions to electricity generation in the Northeast. Onshore wind resources have the technical potential to meet almost half of the region's annual energy needs, while offshore wind resources in New England and the Mid-Atlantic are projected to far exceed the Northeast's current summer generating capacity. The large offshore wind project currently proposed for the Cape Cod region of Massachusetts

A Citizen's Guide to Reducing Emissions in the Northeast

1. **Become carbon-conscious.** The problem of global warming stems from a previous lack of awareness (on every scale, from individual to societal) of our "carbon footprint" and its effect on climate. Fortunately this is rapidly changing. Individuals and families can start by using one of several publicly available carbon footprint calculators[17] that will help you understand which choices make the biggest difference.
2. **Drive change.** For most people, choosing a vehicle (and how much they should drive it) is the biggest single opportunity to slash personal carbon emissions. Each gallon of gas we use is responsible for 25 pounds of heat-trapping emissions; better gas mileage not only reduces global warming but can also save drivers thousands of dollars at the pump over the life of the vehicle. Compare the fuel economy of the cars you are considering[18] and look for fuel-efficient technologies such as hybrid engines. Drive less by making more use of public transportation, carpooling, bicycling and walking for shorter trips, and "bundling" errands to make fewer trips.
3. **Look for the Energy Star label**.[19] When it comes time to replace household appliances, look for the Energy Star label on new models (refrigerators, freezers, furnaces, air conditioners, and water heaters use the most energy). More efficient models may cost a bit more up front, but the energy savings can pay back your extra investment within a couple of years. The Energy Star program, run by the EPA and the Department of Energy, makes it easy to identify products that rank in the top 25 percent for energy efficiency among more than 35 product categories. The program also offers a host of resources for reducing energy consumption in homes and businesses, and identifies new homes designed to use at least 30 percent less energy than construction that merely meets existing building codes.
4. **Choose clean power.** Well over half of the Northeast's electricity comes from fossil fuel-fired power plants. However, consumers throughout the region (except in New Hampshire) can purchase electricity generated from renewable resources that produce no carbon emissions, including wind, hydropower, biomass, and solar. If your local utility does not offer a "green" option you can still purchase renewable energy certificates (RECs) that offset fossil-fuel use by funding renewable energy and energy-efficiency projects elsewhere in the world. RECs that are "Green-e"-certified meet high standards for ensuring the projects they fund reduce heat-trapping emissions.[20]
5. **Unplug an underutilized freezer or refrigerator**. One of the quickest ways to reduce your global warming impact is to unplug a rarely used refrigerator or freezer. This can lower the typical family's CO_2 emissions nearly 10 percent.
6. **Get a home energy audit**. Take advantage of the free home energy audits offered by many utilities. Even simple measures (such as installing a programmable thermostat to replace an old mechanical unit or sealing and insulating heating and cooling ducts) can each reduce a typical family's CO_2 emissions about 5 percent.
7. **Lightbulbs matter**. If every U.S. household replaced one incandescent lightbulb with an energy-saving compact fluorescent lightbulb (CFL), we could reduce global warming pollution by more than 90 billion pounds over the life of the bulbs—the same as taking 6.3 million cars off the road. CFLs now come in all shapes and sizes, and will lower your electric bills along with your emissions.
8. **Buy good wood**. When buying wood products, check for labels that indicate the source of the timber. Supporting sustainable forest management helps conserve biodiversity and may help slow global warming too. Well-managed forests are more likely to store carbon effectively because more trees are left standing and carbon-storing soils are disturbed less.
9. **Spread the word and help others.** A growing movement across the country seeks to reduce individual, family, business, and community emissions while inspiring and assisting others to do the same. The Empowerment Institute based in Woodstock, NY, sponsors a "Cool Community Campaign" featuring a "Low Carbon Diet" study guide; you and other members of your local community can use this resource to help achieve energy savings and emissions reductions.[21]
10. **Let policy makers know you are concerned about global warming.** Elected officials and candidates for public office at every level need to hear from citizens. Urge them to support policies and funding choices that will accelerate the shift to a low-emissions future.

would provide up to 440 megawatts of power and meet three-quarters of that area's electricity needs.

Solar photovoltaic (PV) installations, which convert sunlight directly into electricity, are the fastest-growing energy technology in the world. While still expensive relative to other generation technologies (including other renewable energy technology), the costs continue to decline. And solar power is abundant during the Northeast's times of peak electricity demand, which is driven by air conditioning on hot and sunny afternoons. Use of PV on buildings also eliminates the cost of transmission and distribution, an important additional factor in assessing the technology's cost-effectiveness.

Biomass energy production in the Northeast contributes to renewable electricity and could contribute more, using fibrous wastes from the region's lumber and paper industries, agricultural residues, and "energy crops" such as fast-growing willow or poplar trees as fuel. (See the section on managing forests and agricultural lands for issues related to the sustainable use of biomass.)

Ground-source heat pumps are a proven and fairly common, but still relatively under-utilized, option

New Jersey's Atlantic County Utilities Authority commissioned a five-turbine, 7.5 MW wind farm at its wastewater treatment plant in Atlantic City in 2005. Also featuring a 500 kW solar PV array, it became Atlantic City's most unlikely attraction during its first year of operation, when more than 4,000 visitors toured the site.

SUCCESS STORIES

The University of New Hampshire in early 2006 commissioned an on-campus natural gas-fired CHP plant that now provides greater energy security for the campus along with emissions 21 percent below the previous year. In a few years a 12-mile pipeline now under construction will enable the university to fuel its CHP plant with methane collected at the regional landfill, reducing campus emissions 57 percent below 1990 levels.

Pennsylvania Governor Ed Rendell cut the ribbon in mid-2006 at the South Park Industrial Complex in Cambria County to officially open Gamesa Corporation's first manufacturing facility in North America for wind-turbine generator blades. More than 230 people are expected to work at the new plant. The Spanish wind-energy company is investing $84 million to locate its U.S. headquarters in Philadelphia along with three other plants in the state, where additional workers will produce windmill components.

In January 2007 Framingham, MA-based Staples Corporation unveiled its second rooftop solar PV system in the Northeast (at its retail distribution center in Killingly, CT). At roughly 74,000 square feet—approximately 1.5 times the size of a football field—this 433-kilowatt system is the largest of its kind in New England and provides approximately 14 percent of the facility's annual electricity needs. The system was installed at no capital cost to Staples through a financing and power-purchase agreement with SunEdison. Staples currently ranks fourteenth among the more than 700 partners in the U.S. Environmental Protection Agency's voluntary Green Power Partnership, procuring 20 percent of its total electricity needs from renewable sources.

In 2006 Public Service of New Hampshire's Northern Wood Power Project at Schiller Station in Portsmouth, NH, permanently replaced a 50-megawatt coal boiler with a state-of-the-art wood-burning boiler with the same capacity. As a result, the new boiler is expected to consume more than 400,000 tons of clean wood chips and reduce plant emissions by more than 380,000 tons of CO_2 each year.

for reducing emissions. These electrically powered devices provide heating and cooling by tapping the solar heat stored in the earth below the frost line. Barriers to more widespread use of this highly energy-efficient technology include finding soils that can be drilled for installation of the heat-extracting loops, a possible need for test wells, relatively high capital costs, and the unfamiliarity of many building owners and engineering professionals with the technology. The U.S. Department of Energy funds a national effort and several states including New York operate educational and technical-assistance programs aimed at overcoming these barriers.[22,23]

Nuclear power currently provides about one-third of the region's electricity without emitting CO_2 during generation. However, unresolved issues remain about the operational safety of these plants, their vulnerability to terrorist attack, and the lack of approved long-term storage sites for nuclear waste.[24,25] These concerns make it unlikely that nuclear power generation will expand in the Northeast over the next few decades.

Capturing the mechanical energy of ocean currents, waves, and tides along the Northeast's coastline holds some promise for electricity generation. Technologies are already under development and proposals for pilot projects in Maine, Massachusetts, New York, and Rhode Island have been filed with federal and state authorities. The commercial viability of such projects and the likelihood of public acceptance are not yet clear, however.

Similarly, technologies that would reduce emissions by capturing the CO_2 from fossil fuel-fired electricity generation and either storing it or converting it into a useful product are also under development. In the Northeast, Pennsylvania represents the most promising locale for storing carbon in geologic formations, but the technical viability

SUCCESS STORIES

In 2002, the Rex Lumber Company in Englishtown, NJ, installed a wood waste-fueled boiler to produce heat, electricity, and steam for its industrial processes. By using over 44,000 cubic yards of wood waste and sawdust that was once sent to the landfill, the company eliminated an annual natural gas bill of approximately $100,000. Also, a steam-turbine generator captures excess steam to provide 150 kW of electricity to the facility, which provides an additional $50,000 in savings. Installation expenses were partly supported by the New Jersey Clean Energy Program, and emissions from the wood-waste boiler are well below state and federal standards.[26]

In 2005 Colby College in Waterville, ME, completed a new 27,000-square-foot alumni center heated and cooled by three geothermal wells. Because the temperature of the water supplied by these wells stays consistently in the mid- to upper-50°F range, it is cool compared with ambient air temperatures in the summer and relatively warm in the winter. The annual savings over the proposed alternative, an oil-fired boiler and conventional air conditioning, was estimated at $4,400 based on 2005 energy prices.[27]

and cost-effectiveness of this option is not yet well established.[28]

Opportunities for action

- ***States can continue to improve appliance and lighting efficiency standards***. Even with the standards adopted in many Northeast states in recent years, additional proposed efficiency standards could continue to help lower emissions.[29]
- ***States can adopt an energy-efficiency resource standard.*** Three states in the Northeast (Connecticut, Pennsylvania, and Vermont) have adopted this innovative policy, which requires more efficient generation, transmission, and use of electricity and natural gas.
- ***States and cities can lead by example***. By mandating that their agencies purchase the most efficient lighting and appliances and incorporate energy-efficient design and construction standards into all facilities, state and municipal governments can save money and help expand the market availability of efficient products and services.
- ***States can enact or strengthen renewable electricity standards.*** Eight of the Northeast's nine states require that an increasing portion of electricity supply within their state come from renewable sources. Strengthening the existing standards (as many states across the country have already done) will further reduce the electricity sector's contribution to global warming.[30]
- ***States and cities can enact policies that promote customer-based electricity generation.*** In 2007 only a few of the Northeast's states and cities had comprehensive measures in place to facilitate the widespread installation of small-scale electricity generation from renewable resources or efficient, clean CHP systems. New York City has recently announced its intention to require that major construction projects fully evaluate the technical and economic potential of supplying their own electricity and heat. In addition, regulatory barriers can be greatly reduced.[31]
- ***States can improve net-metering policies.*** All of the Northeast's states have net-metering policies that enable customers with on-site power-generation capability (renewable energy or CHP) to sell excess electricity to their utility, thus making the installation more cost-effective. However, other changes are still needed to remove restrictions that can prevent the full value of these investments from being realized.
- ***States can adopt or expand tax incentives for small-scale renewable electricity generation and efficiency.*** Several of the Northeast's states have adopted tax policies that support renewable electricity generation by exempting the equipment from property tax valuations, providing income tax credits and deductions for the purchase and installation costs, or exempting the equipment from state sales taxes.[32]

The Regional Greenhouse Gas Initiative (RGGI)

Ten northeastern states have created a regional plan and a model rule for states to reduce CO_2 emissions from the electric-power sector. The approach, commonly referred to as "cap-and-trade," harnesses market forces by establishing a limit (or cap) on the sector's overall emissions and requiring every power plant to obtain an allowance for each ton of carbon it emits.

All 10 states are developing rules to implement the program starting January 1, 2009. The rules will stabilize CO_2 emissions at their 2005 level through 2014, then reduce emissions 10 percent by 2019. Importantly, several states have committed to auctioning 100 percent of the allowances created by the program, maximizing expected revenues. The wise investment of these revenues in energy efficiency and new renewable energy could help offset any increases in electricity prices.

An analysis of RGGI's potential economic impact concluded that a doubling in funds for the region's existing energy-efficiency programs would deliver savings on consumer energy bills and positive effects on energy security, economic output, personal income, and employment.

Buildings

The Northeast's relatively old stock of residential, commercial, and industrial buildings offers wide-ranging opportunities to reduce the emissions associated with water- and space-heating needs. The federal Energy Star Buildings program, for example,

Pittsburgh's David L. Lawrence Convention Center opened in September 2003 as the world's first certified "green" convention center. Encompassing nearly 1.5 million square feet on a former "brownfield" site adjacent to public transportation routes, its daylighting design provides natural light for 75 percent of the convention center's exhibition space, saving 9.5 million kWh of electricity a year. The building uses about 35 percent less energy than a conventionally designed building of comparable size.[33]

provides a "better than building code" framework that includes strategies and tools for upgrading the energy efficiency of most types of existing buildings. The additional cost of designing and constructing a new building that qualifies for Energy Star status ranges from zero to just a few percent. In addition, such buildings cost significantly less to operate, provide greater comfort, and typically generate 10 to 30 percent lower emissions than buildings that merely comply with local building codes.

Energy efficiency is also incorporated into the broader discipline of "green building," which embraces a portfolio of strategies and technologies to produce energy-, water-, and resource-efficient buildings that also have good indoor air quality, take advantage of natural lighting, and create minimal disruption to the environment around the building site. A recent study found that the financial benefits of green design and construction amount to more than 10 times the additional up-front cost; such projects reduce emissions, environmental damage, and energy, waste, water, operating, and maintenance costs while increasing occupant productivity and health.[34]

The construction of homes that generate energy from renewable sources and, on an annual net basis, produce as much energy as they draw from the grid (so-called Zero Net Energy Homes) is now feasible in the Northeast. Though the task is challenging in a region with significant home heating requirements, highly efficient designs that incorporate ground-source heat pumps and solar PV systems can require only one-fifth the energy of homes built to meet existing codes. Owners of such homes can also purchase whatever supplemental energy they require from their utility in the form of zero-emissions electricity generated from renewable resources rather than fossil fuels.

Opportunities for action

- ***States can continue to update and strengthen enforcement of building energy codes.*** Building codes in the Northeast's states have not kept pace with technological innovation, resulting in energy use (and emissions) 15 to 30 percent higher than Energy Star standards. Stronger implementation and broadening of these codes (e.g., to include minimum standards for air leaks, insulation, doors, and windows) could significantly reduce emissions and increase savings.[35]
- ***States can require that all building sales and apartment rentals be accompanied by an energy rating and cost certificate.*** Providing the real estate market with information about a building or home's energy supply, average and peak usage patterns, and costs of operation would create an incentive for greater efficiency and encourage regular upgrades to HVAC systems and other building components such as windows that affect energy use.
- ***States can explore the creation of an "energy extension service."*** Such a service, operated by the state university system, could educate building owners about energy-efficient options while spurring on-campus innovation.
- ***Cities and towns can use zoning laws to encourage energy-efficient and "green" development.*** Zoning laws can require (or offer incentives) to building owners and developers to meet the U.S. Green Building Council's LEED certification and/or the EPA's Energy Star standards. In January 2007, for example, the City of Boston amended its zoning code to require all new construction, additions, or renovations larger than 50,000

square feet to meet the first level of LEED certification.[36]

- ***States and cities can provide sales and property tax incentives for the installation and operation of energy-efficient systems.*** Exempting energy-efficient appliances, lighting, motors, and building systems (e.g., insulation, replacement windows) from sales tax would encourage their wider use. Tax incentives could also be used to encourage developers and builders to design highly efficient neighborhoods or industrial parks and use available technologies for reducing emissions from HVAC systems.

Transportation

The transportation sector represents the Northeast's largest source of CO_2 emissions. Although most policies for reducing vehicle emissions are best implemented at the federal level, there are numerous examples of successful local, state, and regional policies such as sustained investment in public transportation systems, incentives for private and commercial fleet owners to purchase low-emissions vehicles, direct financial support and infrastructure investments to promote the substitution of biodiesel and natural gas for petroleum diesel, and requirements and incentives aimed at curbing growth in total vehicle miles traveled.

The most efficient gasoline-electric hybrid vehicles currently available can reduce emissions as much as 60 percent, and so-called "plug-in" hybrids that recharge their batteries while the vehicle is parked could surpass this once they are made available in the United States. The performance and local air-quality benefits of biodiesel and compressed natural gas (CNG) compared with petroleum diesel have been widely demonstrated by a number of municipalities, universities, and mass-transit fleets, including Keene, NH, the state universities of New Hampshire and Vermont, metropolitan Boston's Massachusetts Bay Transportation Authority (MBTA),

The Solaire apartment building, a 27-story, 293-unit residential tower in Battery Park City, achieved LEED "Gold"-level certification through aggressive goals for reducing energy and water use and peak electricity demand. Completed in 2003, its features include optimal use of daylight, thermal efficiency, high-performance windows, programmable digital thermostats, and Energy Star appliances and lighting fixtures in each unit. Photovoltaic (PV) panels generate 5 percent of the building's peak electricity.

SUCCESS STORY

Manhattan's new 55-story Bank of America Tower, scheduled to open in 2008, will use much less energy than a standard office building because of its efficient design and extensive use of daylighting, LED lights, and CHP systems for heating and cooling. Extensive use and local sourcing of recycled steel, plastic, glass, and other materials also serves to reduce the emissions associated with this major development.[37]

and New York City's Metropolitan Transit Authority (MTA).

More widespread use of biodiesel and CNG would offer immediate opportunities for significant emissions reductions in both urban and agricultural settings across the Northeast. (See the Renewable Energy on the Farm text box.)

In contrast, ethanol offers limited climate benefits because it is currently produced primarily from corn in an energy-intensive process. This may change in the future with further development of technology for producing "cellulosic" ethanol from agricultural waste or other plant material such as willow and switchgrass.

Opportunities for action

- ***States can adopt California's vehicle emissions standards.*** California has adopted emissions standards for automobiles that require reductions of approximately 30 percent below 2002 levels by 2016, beginning with the 2009 model year.[38] Under the Clean Air Act, California is the only state in the nation with the right to enact its own air-pollution standards, but other states may follow suit once the EPA grants California a waiver. Pending this waiver, Connecticut, Maine, Massachusetts, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and several other states plan to implement the California standard.
- ***States can adopt low-emissions vehicle incentives.*** Offering incentives for low-emitting vehicles and levying surcharges on the highest-emitting vehicles is known as a "clean car discount" program. Such a program can be self-financing if the surcharges fund all of the rebates and administrative costs associated with the program.
- ***States can adopt low-carbon fuel standards.*** California has established a statewide goal of reducing heat-trapping emissions from its transportation fuels at least 10 percent by 2020, and several other states are pursuing similar approaches.[40]
- ***State insurance commissions can implement pilot "insurance at the pump" programs.*** Tying the level of basic liability insurance drivers must carry to the amount of fuel they purchase would raise their awareness of the implications of their vehicle choices and operating practices.[41] Coordination among the states would enhance the effectiveness of this approach and reduce out-of-state fuel purchases.[42]
- ***States, cities, and corporations can develop and expand fleet initiatives.*** Replacing entire automobile fleets with hybrids and other fuel-efficient vehicles, as cities such as Medford, MA, and a number of universities have already done, can

As part of a sweeping sustainability initiative called plaNYC, New York City Mayor Michael Bloomberg put forward a detailed proposal to reduce vehicle traffic during peak hours in Manhattan through "congestion pricing," thus reducing emissions and improving air quality. He also announced that by 2012, all of the approximately 13,000 taxis in the New York City fleet must be a hybrid-powered vehicle that gets at least 30 miles per gallon.[39] plaNYC has set an overall goal of reducing the city's energy use 30 percent by 2017.

SUCCESS STORY

New Jersey's largest electric and gas utility, PSE&G, announced plans in May 2007 to replace 1,300 vehicles— including cars, light trucks, and "bucket trucks"—with hybrids over the next decade. Along with the use of biodiesel and installation of electric lifts on remaining diesel-powered trucks, PSE&G estimates the changes will reduce its carbon emissions by over 81,000 tons of CO_2.[43]

reduce emissions and long-term fleet operating costs while helping to expand the market for low-emissions vehicles. Because fuel-efficiency improvements are not as widely available for the heavy-duty vehicles used in public transportation fleets, reducing emissions could involve the use of cleaner fuels such as natural gas and biodiesel.

- ***States and cities can use infrastructure funds to shape transportation patterns.*** Massachusetts alone spends some $4 billion a year on infrastructure development that creates opportunities to reduce vehicle emissions through "smart growth" practices. These include concentrating development near public transportation options, increasing the number of such options, and making optimal use of existing infrastructure and building sites before developing new sites.[44]
- ***Cities and towns can use property tax policies to reduce sprawl.*** Property tax incentives can encourage new construction in already urbanized areas, while tax levies can discourage construction on undeveloped land. Tax and regulatory incentives can also reduce sprawl by encouraging development in clusters.

Industry

The energy consumed by industrial and manufacturing processes accounts for a significant proportion (12 percent) of the Northeast's emissions. While more energy-efficient technologies and processes can certainly reduce these emissions, companies can also greatly reduce their emissions while lowering their energy expenses by making use of energy-efficient building and facility designs, on-site renewable energy generation, and CHP systems. Industries can also lower the total energy cost of production by making more use of local sourcing, recycled raw materials, and efficient transportation systems.

A number of major companies in the Northeast, including IBM and United Technologies, have successfully set corporate emissions-reduction targets and developed company-wide performance goals based on energy use, raw-material inputs, and emissions rates, and are using these metrics to drive process improvements and product redesigns. IBM, for example, set out to achieve a 4 percent reduction in its average annual heat-trapping emissions from 2000 to 2005 by increasing energy efficiency and expanding its use of renewable energy. The company exceeded its goal by more than 50 percent, achieving average annual reductions of 162,000 metric tons (or 6.2 percent).[45]

CHP technologies represent a particularly promising strategy for industry. (See the electric power section.) By recovering much of the heat released during electricity generation and using that energy for water and space heating and air conditioning, CHP systems can harness as much as 80 percent of a fuel's useful energy—a highly cost-effective means of achieving substantial emissions reductions.[46]

Opportunities for action

- By installing on-site renewable energy systems and CHP technologies, industries can reduce emissions while enhancing their energy security and reducing their exposure to volatility in the global fossil-fuels market.
- Industries can purchase electricity generated from renewable energy sources, and purchase carbon offsets for unavoidable corporate travel.
- Industries can also strive to develop products that produce lower levels of heat-trapping emissions during manufacture and/or disposal.

Cornell University's Transportation Demand Management Program is an example of what dedicated and sustained investment in public transportation systems can achieve. Faced in the early 1990s with an apparent need for 2,500 new parking spaces, the university instead worked with local authorities to enhance the region's public transportation system. Through a package of service improvements, incentives, and support for carpooling and use of public transportation, the university estimates that by 2005 it had saved more than $40 million in construction, infrastructure, and transportation costs while enhancing air quality and preserving open space on campus.[47]

Forest and agricultural land management

Trees and other vegetation store carbon and thus can play an important role in slowing global warming. Over the past century, forests across the Northeast have grown back onto lands that had once been cleared for farming, drawing CO_2 out of the atmosphere through photosynthesis and storing the carbon in plant tissues, thus reducing the region's net contribution to climate change.

Forest-management practices affect the amount of carbon a forest can store as well as the amount released by trees when they are cut down for timber. Opportunities for capturing carbon or avoiding CO_2 emissions from forests include protection, reduced-impact timber harvesting, and reforestation. Forests managed in a sustainable manner can help slow global warming by storing carbon, replacing more energy-intensive building materials such as concrete, and displacing fossil fuels as a source of energy.

Over the next few decades rising atmospheric concentrations of CO_2 along with a warmer climate and longer growing season are likely to increase carbon storage in the Northeast's forests. But these gains may be offset if forests are extensively cleared for development, release CO_2 due to unsustainable timber harvesting practices, or are more frequently or severely damaged by climate-related insect or disease outbreaks, storms, fire, or other disturbances. (See the forests chapter.)

Management practices in both forests and on farms also affect the amount of carbon stored in soils. Sustainable forestry and farming practices can increase the amount of carbon-storing organic matter in soils and reduce or eliminate the use of synthetic nitrogen fertilizers, which are extremely energy-intensive to produce and release heat-trapping nitrous oxides (N_2O).[48] Even organic nitrogen fertilizers such as manure and compost can increase N_2O emissions if used inefficiently.

Excessive tillage on farms, which has been common practice for decades, accelerates the decomposition of organic matter in soils, resulting in the rapid loss of stored carbon. "No-till" or reduced-tillage farming methods, which cause less soil disturbance and erosion than plowing, reduce CO_2 emissions from soils and help increase the organic matter in soils (which also benefits crop production and water-holding capacity).

"Cellulosic" ethanol derived from fast-growing vegetation such as poplar trees or switchgrass may become an important renewable source of energy to add to the portfolio of fossil-fuel alternatives. Because farmers in the Northeast and elsewhere are considering the long-term profit potential of entering the "fuel crop" marketplace, policy makers must consider the sustainability and full range of implications of these alternatives. For example, beef, poultry, and other meat producers are already feeling the pinch of higher feed prices due to increasing demand for corn-derived ethanol.

If poorly managed, production of cellulosic ethanol can strip fields of all aboveground biomass, leaving little organic matter and important plant nutrients such as nitrogen and phosphorus to recycle back into the soil. This could lead to degraded soils that require energy-intensive inputs such as nitrogen fertilizers to sustain productivity. Any expansion of the acreage devoted to cellulosic ethanol fuel stocks should therefore be preceded by careful land-use planning.

More broadly, forestry and agricultural policies in the Northeast can be designed to promote better management practices and systems that reduce emissions and support the sustained profitability of the region's foresters and farmers. Such practices, already being put into place by many, include increased carbon capture in soils, more efficient use of nitrogen fertilizers, reduced on-farm use of fossil fuels, and expanded use of renewable energy resources including wind and biomass produced in a sustainable manner. (See the Renewable Energy on the Farm text box.)

SUCCESS STORY

In 2002 Harbec Plastics, a precision injection-molding company near Rochester, NY, installed a bank of 25 natural gas-fueled microturbines to provide 100 percent of the factory's electricity. This CHP system captures the heat released during power generation for use elsewhere in the factory—even for air conditioning (through the use of an absorption chiller).[49]

Opportunities for action

- States can establish standards for the use of biomass and biofuels that incorporate multiple sustainability criteria, so that biomass production does not compromise the value of other environmental services provided by forest and agricultural ecosystems.
- States can provide incentives for woody and agricultural biomass-energy systems that use these resources in the most efficient and sustainable manner possible. The Biomass Energy Resource Center in Vermont, for example, is working closely with many New England communities to develop sustainable community-scale biomass-energy systems that provide both electricity and heat at high levels of efficiency using small-scale CHP systems.[50]
- Policy makers can develop integrated state and regional plans for managing forested lands that maximize the suite of services forests provide, including carbon storage, timber, wood as fuel and as a feedstock for ethanol production, as well as clean water, erosion control, and biodiversity.
- To maintain or enhance carbon storage in the forests of the Northeast:
  - Policy makers can make carbon storage an explicit objective of public and private forest management in the Northeast and an explicit criterion for certification of sustainable forest management.
  - The timber industry can expand use of reduced-impact timber harvesting in production forests in the Northeast.

Methane recovery

Methane, which is released directly into the atmosphere from livestock, sewage treatment plants, and landfills, is a potent heat-trapping gas. The EPA's Landfill Methane Outreach Program works with landfill owners, communities, states, utilities, power marketers, project developers, Native American tribes, and nonprofit organizations to encourage the recovery of methane from landfills and its conversion into energy. The program helps assess project feasibility, find financing, and market the benefits to local communities. As of April 2007 the EPA reports that 10 northeastern states have 46 operational projects, but almost exactly twice that number of landfills have potential that remains untapped.[51]

In addition, farmers across the Northeast are adopting innovative approaches to capturing and using methane to power farm operations. (See the Renewable Energy on the Farm text box.)

Willow shrubs grown in the Northeast have potential as a feedstock for both transportation biofuels and stationary bioenergy. Because the cost of harvesting and delivery can account for 40 to 60 percent of its delivered cost, the State University of New York's College of Environmental Science and Forestry, Case New Holland Corporation, and Cornell University have been collaborating on the design of new types of equipment to increase harvesting efficiency (in hopes of making willow a viable "energy crop" for Empire State farmers).

Opportunities for action

- States, communities, and large institutions can combine resources and collaborate (with help from the EPA) to transform landfill methane—often a local and regional nuisance—into an asset that reduces heat-trapping emissions, replaces fossil fuels, provides jobs, and enhances regional energy security. (See the University of New Hampshire success story in the electric power section.)

ADAPTING TO UNAVOIDABLE CLIMATE CHANGE IN THE NORTHEAST

Human-induced climate change is under way, and past emissions guarantee some further warming over the next few decades. Adapting to the economic and ecological stresses that will accompany this warming has therefore become a necessary complement to the urgent need to reduce heat-trapping emissions. The Northeast's policy makers and resource managers must now begin preparing for the unavoidable consequences of climate change by supporting the timely implementation of adaptation plans, particularly in vulnerable sectors and communities. The degree of adaptation the region will need depends substantially on our near-term success in reducing emissions.

We must ask ourselves whether, by mid-century, we will be well on our way to making the necessary cuts in emissions and effectively addressing unavoidable changes, or only belatedly coming to terms with the costly, socially disruptive, and technologically daunting consequences of continued high levels of emissions. Addressing many of the changes anticipated in this report would be significantly more manageable and affordable under the lower-emissions scenario than under the higher-emissions scenario, and even deeper reductions than those assumed by the lower-emissions scenario are feasible.

Taking action to prepare for the likely consequences of climate change, while not cost-free, can prove to be less expensive than the economic damage that would result from doing nothing.[52,53] Less-affluent people and communities, even in relatively wealthy regions such as the Northeast, will be among the hardest hit by global warming in part because they can least afford to prepare for or cope with the impacts (such as extreme heat) once they occur. Similarly, small or geographically isolated businesses may have fewer resources and available options for coping with climate change. And, as this report makes clear, some economically important species such as cod and lobster as well as other species of great intrinsic value such as the Bicknell's thrush will soon cross climate-related thresholds beyond which they will lose critical habitat or other conditions necessary for their continued survival. (See the forests and marine chapters.)

We therefore have a moral obligation to focus attention on the plight of vulnerable communities, sectors, and ecosystems and to increase their resilience to climate change—an outcome essential to the economic and ecological sustainability of the region as a whole. Decision makers, however, need a better understanding of the factors that contribute to climate vulnerability and the full suite of options that are available to reduce that vulnerability. Well-designed social or resource-management policies, for instance, could substantially enhance the region's ability to adapt.

Moving swiftly to reduce vulnerability is also smart economics. For example, governments, businesses, and communities that plan ahead will be

In 1996 New York dairy farmer Bob Aman installed a manure storage and anaerobic digester system to reduce odors on his 500-cow property. In 2004 the generator produced nearly 400,000 kilowatt-hours of electricity, more than what the farm used that year.

Renewable Energy on the Farm

Methane recovery. In 2006 the Shrack family farm in Loganton, PA, started using an anaerobic digester to capture methane gas from cow manure and use it to produce electricity. Waste heat is used in part to replace oil-generated heating on the farm. The electricity generated by the system displaces electricity formerly drawn from the grid, reducing CO_2 emissions by an estimated 630 tons per year, and also avoids the release of methane emissions equivalent to an estimated 1,550 tons of CO_2 per year.[54]

Biofuels. Boiling tree sap to produce maple syrup is an energy-intensive process, so Dan Crocker, the largest maple syrup producer in southern Vermont (with an average output of 5,500 gallons per year), has converted his sugar house to run on used vegetable oil collected from local restaurants rather than regular fuel oil. Because vegetable oil is derived from plants its combustion adds little CO_2 to the atmosphere compared with oil derived from fossil fuels. Crocker also saves money because the used vegetable oil is about a dollar per gallon less expensive than regular oil.[55]

Some vegetable farmers in Vermont, such as Richard Wiswall and John Williamson, have also begun using vegetable oil to heat their greenhouses and run farm equipment. Wiswall collects used oil from local restaurants' deep fryers and makes his own biodiesel from it. Williamson is attempting to achieve energy independence for his operations by growing high-energy oilseed crops such as canola and mustard to produce biodiesel, and also ferments sorghum to produce ethanol.[56]

positioned to take advantage of the possible benefits of climate change, as in the case of fishing communities that face the loss of nearshore lobster fisheries but could instead harvest high-value shellfish better adapted to warm water (or further diversify their fishing fleets to take advantage of warm-water fish moving north). Similarly, many communities in the Northeast that are modernizing their water and sewer infrastructure could protect their investments by incorporating near-term projections of more extreme rainfall into their plans.

In other words, decision makers should draw on our best scientific understanding of climate change and societal vulnerabilities, then carefully consider the likely efficacy and broader implications of different adaptation strategies. Policies that aim to reduce the population, infrastructure, and economic activity in coastal floodplains, for example, must minimize the negative impacts on local businesses, facilitate relocation to higher ground, provide adequate compensation where necessary, avoid additional environmental damage, and rehabilitate threatened habitats.

With its successful high-tech sector, cutting-edge public-health institutions, high-quality public education, overall wealth, and enormous academic "capital," the Northeast has the capacity to meet the challenge of climate-change adaptation. Yet, as in other regions, this capacity has not always been fully utilized. Instead, severe flooding in 2006, record-setting nor'easters in the 1990s, and the ice storm of 1998 illustrated the region's vulnerability to such extremes.

Global warming will create additional stresses on people and their environment and place growing demands on the Northeast's ability to anticipate, prepare for, and respond to climate changes. Even modest sea-level rise, for example, when combined with storms similar in frequency and intensity to those experienced today, can inflict heavy damage on the region's coastal infrastructure. Likewise, extreme heat threatens the health of an aging population. It is therefore not the region's capacity to adapt but its ultimate actions that will determine the severity of global warming's impact on the Northeast.

A delay in preparing for anticipated changes—or a continued reliance on infrastructure and emergency response plans based on historical experience rather than projected conditions—will increase the region's exposure to climate risks. The adaptation strategies most relevant to (and feasible for) any specific community or economic sector must be assessed on a case-by-case basis that addresses the various technological, policy, financial, social, ecological, and ethical considerations. Any one of these factors may impose important constraints on the community's ability to adapt.

Using technologies wisely

Technological solutions for reducing climate vulnerability include seawalls for protection against rising seas, crop varieties better adapted to warmer conditions and longer growing seasons, and air conditioning to cope with summer heat waves. Some technologies may provide only temporary relief or none at all, or may have unintended side effects. Snow-dependent winter recreation provides a good example of the costs and limitations of using technology to cope with climate change: snowmaking equipment may provide an economically and technically feasible means of helping the alpine-skiing industry cope with warmer winters (albeit with water and energy costs and certain ecological implications), but it is not a feasible solution for snowmobiling. (See the winter recreation chapter.)

Even for industries where technological solutions are available, managers must weigh the cost and timing of the transition to new technologies during what may be decades of quixotic weather.

Beaches will become more vulnerable to erosion as sea level rises, and neighboring homes will become more vulnerable to damage from coastal flooding. Efforts to replenish beach sand, like that undertaken at Brant Beach on Long Beach Island, NJ (shown here), can help protect property and coastal tourism. As rising sea level drives greater erosion, however, these efforts may need to be repeated much more frequently and thus become more costly.

The frequency of droughts is projected to increase over the coming decades under the higher-emissions scenario, with little change projected under the lower-emissions scenario. Drought and hot summer conditions would increase irrigation needs, particularly for growers of traditionally rain-fed crops (common in the Northeast). Farmers may be able to cope by investing in and upgrading irrigation systems, assuming the up-front and long-term operational costs are within reach.

The commercial timber industry, for example, may adapt to warmer winters by switching to equipment that allows harvesting on unfrozen ground, but industry managers would need a clear climate signal in order to make this costly change. (See the forests chapter.)

Technological solutions can also seduce us into believing that a problem can be solved at the operational level, without requiring deeper systemic changes. Before embracing such solutions, therefore, policy makers must carefully weigh the environmental and social consequences by asking a set of questions starting with: who can *afford* to adopt the technology and who cannot? For example, are small farms as able as large farms to install costly air-conditioning equipment that would maintain dairy production in a warmer climate?

Because global warming is already upon us and some amount of additional warming is inevitable, adapting to higher temperatures is now an essential (and complementary) strategy to reducing emissions.

Also, who first learns about new technologies (e.g., new genetic crop varieties, more efficient irrigation technologies) and can afford to invest in them, and at what pace? Does the technology (e.g., switching from cod to shellfish farming, investing in new fishing boats and gear) strengthen or undermine the social fabric of specific communities? What advantages, disadvantages, or risks accrue to those who adopt the technology first compared with those who must wait? And finally, how can the prospects for "win-win" conditions be enhanced? For example, is it possible to ensure that bacteria engineered to halt the spread of an invasive pest will not create new ecological problems?

Addressing underlying social inequities

As the questions asked above suggest, the ability to cope with and adapt to change is highly variable across populations, economic sectors, and even geographic regions. Climate change thus has the potential to aggravate resource constraints, social inequalities, and even public-health disparities among different communities in the Northeast: the region's urban populations—particularly the elderly, the very young, and the poor—suffer most from the stress of extreme heat. (See the health chapter and the text box on social vulnerability.)

In many instances, people's vulnerability to climate change is related to limited and climate-sensitive career options. Maine fishermen and women who can no longer make a living off groundfish such as cod, for example, have switched to lobster fishing, but if this fishery should suffer from lobster-shell disease or a decline in the survival and growth of young lobsters, few income-generating alternatives will be readily available. (See the marine chapter.)

It must be noted that global warming also presents opportunities to enhance economic development, human well-being, and social and environmental equity in the Northeast. In the countryside, small family farms—often vulnerable to economic trends and weather extremes—may be less capable of responding to the demands of a changing climate than industrial farms with greater resources, but the fact that many small farms are highly diversified in terms of the crops and livestock they produce could position them to take advantage of changing opportunities. In cities, efforts to build emergency-response systems and support networks (e.g., "buddy systems" among neighbors during heat waves) may yield dividends in the form of new and stronger community ties. (See the health chapter.)

Strengthening policies and institutions

Institutions—not just physical organizations but the regulations, rules, and norms that guide behavior—can also influence people's access to information and therefore their ability to use that information in decision making. Environmental-protection legislation, anti-discrimination policies, market regulations, and common expectations about socially acceptable behavior are all examples of such institutions. Well-functioning institutions can provide stability in an otherwise volatile environment, but when the environment changes fundamentally or rapidly—as is expected during this century due to climate change, especially if the higher-emissions scenario prevails—institutions can fail to serve their intended functions and hinder our ability to adapt.

In the marine sector, for example, federal policies have prevented the Northeast's fishermen and women from maintaining multiple fishing licenses and switching between target species as conditions warrant—a practice commonly used in the past when particular fish stocks declined in abundance. (See the marine chapter.) In the face of declining commercial fishing options due to climate change and other environmental stressors, new adaptation strategies may be needed, such as community-based fishery management (which would involve authorities from all levels of government and regional cooperatives).

In the Northeast's heavily developed and densely populated coastal zone, options for managing the mounting risks related to global warming are constrained by past development and land-use patterns, coastal laws and regulations, and the expectations

Warming waters are projected to change the Northeast fishing industry, placing added pressure on both fish stocks and those who fish for a living. As the Northeast climate changes and certain mainstays of the fishing industry (such as lobster) are pushed northward or into deeper waters, some fishermen and women may be able to switch to harvesting different species, provided investments in new fishing equipment are affordable.

How to Prioritize Adaptation Strategies

The various strategies with which states, business sectors, and communities in the Northeast can prepare for climate change must be considered on a case-by-case basis. Each constituency is unique in the challenges it faces and its ability to adapt. However, the following principles can help set priorities:

1. **Monitor the changing environment.** Decision makers and resource managers must keep informed about the specific consequences of global warming for their region and areas of oversight. In particular, improved monitoring of both the climate and the condition of natural systems can give decision makers clearer signals about the need for action and more time to formulate appropriate adaptation strategies.
2. **Track indicators of vulnerability and adaptation.** Monitoring both the progress of specific adaptation strategies and the social factors that limit a community's ability to adapt can enable decision makers to modify adaptation strategies and improve outcomes.
3. **Take the long view.** Decisions with long-term implications (e.g., investments in infrastructure and capital-intensive equipment, irreversible land-use choices) must be considered in the context of climate projections.
4. **Consider the most vulnerable first.** Climate-sensitive species, ecosystems, economic sectors, communities, and populations that are already heavily stressed for non-climatic reasons should be given high priority in policy and management decisions.
5. **Build on and strengthen social networks.** Ties between trusted individuals and organizations are an asset for adaptation at the community level and within business sectors. Strong leaders can inspire organizations in times of difficult change, and well-connected and well-informed individuals can disseminate information that may be critical for effective adaptation.
6. **Put regional assets to work.** The Northeast has an enormous wealth of scientific and technological expertise in its universities and businesses that can be harnessed to improve our understanding of adaptation opportunities and challenges.
7. **Improve public communication.** Regular, effective communication with and engagement of the public on climate change helps build our regional capacity to adapt.
8. **Act swiftly to reduce emissions.** Strong, immediate action to reduce emissions, in the Northeast and globally, can slow climate change, limit its consequences, and give our society and ecosystems a better chance to successfully adapt to those changes we cannot avoid.

that past policies have fostered among property owners. Coastal managers face an increasingly dynamic shoreline that will require regulations based on projected risks rather than historic risks. (See the coastal chapter.)

Institutional mechanisms such as "risk spreading"—accomplished chiefly through insurance—have the potential to ease the risks of climate change, and as a center of the U.S. insurance industry, the Northeast has an opportunity to play a lead role in shaping the industry's response to climate change. (See the text box on coastal insurance.) Insurance is likely to play an important role in helping coastal residents and businesses improve their ability to cope with and recover from coastal storms. Public education about the changing exposure to climate risks along the Northeast's coastline will also need to be linked to strict enforcement of building codes and land-use regulations, and perhaps mandatory insurance coverage (especially for lower-income individuals).

In summary, industries, communities, and individuals in the Northeast have, over time, developed ways to deal with the region's highly variable climate.

This proven adaptability suggests that the Northeast has the resources and experience to cope with global warming. Because of the rapid rate and widespread impacts of the expected climate changes, however, immediate and sustained action by policy makers and resource managers—together with the engagement of the region's substantial scientific and technological expertise—will be needed to avoid the most dangerous consequences of global warming.

CONCLUSION

Climate change represents an enormous challenge, but the solutions are within reach if we act swiftly. Because global warming is largely caused by humans, people also have the power to change its course. Concerted actions to reduce heat-trapping emissions—on the order of 80 percent below 2000 levels by mid-century and just over 3 percent per year over the next few decades—will keep temperatures and the associated impacts from rising to the level of the lower-emissions scenario used in this study.

Because global warming is already upon us and some amount of additional warming is inevitable, adapting to higher temperatures is now an essential (and complementary) strategy to reducing emissions. Delay in reducing emissions increases the costs—and limits the feasibility—of adaptation, while aggressive steps to reduce emissions improve the likelihood that ecosystems and societies will be able to find effective ways to adapt. For each adaptation measure considered, policy makers and managers must carefully assess the potential barriers, costs, and unintended social and environmental consequences.

Of course, actions in the Northeast alone will not be sufficient to meet the climate challenge. Fortunately, many other states are also stepping up. California and several other states, for example, have begun putting precedent-setting policies and practices for reducing emissions into place. As both a global leader in technology, finance, and innovation and a major source of heat-trapping emissions, the Northeast is well positioned to help drive further national and international climate progress. As described throughout this chapter, many individuals, communities, businesses, and policy makers across the region have already taken innovative steps to do just that.

Now we must build upon these first steps through a strong and sustained effort (well-coordinated among governments at all levels, businesses, civic institutions, and individuals) to adopt policies, programs, and practices that will accelerate the adoption of clean, efficient energy choices and timely, forward-looking strategies for adapting to unavoidable climate changes.

The costs of delay are high. Given the century-long lifetime of CO_2 in the atmosphere, the longer we delay, the larger and more aggressive and costly our emissions reductions will need to be in order to limit the extent and severity of climate change.[55] If, for example, U.S. emissions continue on a "business as usual" path through 2020, we would have to reduce our nation's emissions about 9 percent per year from 2020 to 2050 to avoid the impacts described in this report.

Concerted actions to reduce heat-trapping emissions—on the order of 80 percent below 2000 levels by mid-century and just over 3 percent per year over the next few decades—will keep temperatures and the associated impacts from rising to the level of the lower-emissions scenario used in this study.

What is required is an energy revolution of the kind that occurred a century ago as the nation shifted from gaslights and buggies to electricity and cars. In 1905 only 3 percent of U.S. homes had electricity, virtually none had cars, and few could envision how these innovations would transform America and its economy half a century later. Similarly, slightly less than 3 percent of current U.S. electricity demand is met by non-hydroelectric renewable energy, but the fact that we accomplished a dramatic transformation of our energy economy only a century ago suggests that, with foresight and perseverance, we can do it again.

The actions highlighted here for meeting the climate challenge are consistent with and complementary to other widely shared goals such as enhancing our energy and economic security, creating jobs, producing cleaner air, and building a more sustainable economy (the Northeast has very little fossil-fuel resources of its own). The Northeast's states and their municipal governments have a rich array of proven strategies and policies at their disposal to meet the climate challenge in partnership with businesses, institutions, and an increasingly supportive public. The time to act is now.

Endnotes

BY CHAPTER

Executive Summary

1 Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: Impacts, Adaptation and Vulnerability,* Summary for Policymakers. Cambridge, UK: Cambridge University Press. In press. Online at *http://www.ipcc.ch/SPM6avr07.pdf.*

2 Northeast Climate Impact Assessment (NECIA). 2006. *Climate Change in the U.S. Northeast. A Report of the Northeast Climate Impacts Assessment*. Cambridge, Massachusetts: Union of Concerned Scientists.

3 Intergovernmental Panel on Climate Change (IPCC). 2007b. *Climate Change 2007: Mitigation of Climate Change*, Summary for Policy Makers. Cambridge, UK: Cambridge University Press. In press. Online at *http://www.ipcc.ch/SPM040507.pdf.*

4 The definition of carbon dioxide equivalent (CO_2-eq) is the amount of CO_2 emission that would cause the same radiative forcing as an emitted amount of a well mixed greenhouse gas or a mixture of well mixed greenhouse gases, all multiplied with their respective GWPs to take into account the differing times they remain in the atmosphere. Source: Intergovernmental Panel on Climate Change (IPCC). 2007c. *Climate Change 2007: The Scientific Basis*, Summary for Policy Makers. Cambridge, UK: Cambridge University Press. In press. Online at *http://www.ipcc.ch/SPM2feb07.pdf.*

Chapter One
OUR CHANGING NORTHEAST CLIMATE

1 This report focuses on climate change associated with global warming. We use the UN Framework Convention on Climate Change definition of climate change: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

2 Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: Impacts, Adaptation and Vulnerability,* Summary for Policymakers. Cambridge, UK: Cambridge University Press. In press. Online at *http://www.ipcc.ch/SPM6avr07.pdf.*

3 Northeast Climate Impacts Assessment (NECIA). 2006. *Climate Change in the U.S. Northeast. A Report of the Northeast Climate Impacts Assessment*. Cambridge, Massachusetts: Union of Concerned Scientists (UCS).

4 National Oceanic and Atmospheric Administration (NOAA). 2007. NOAA says U.S. winter temperature near average; Global December-February temperature warmest on record. *NOAA magazine* s2819. Online at *http://www.noaanews.noaa.gov/stories2007/s2819.htm.*

5 Narcissus "Rjinveld's Early Sensation", which normally begins flowering at the New York Botanical Garden in early March, was in full flower from the 1st of January, 2007, through the 15th. The plants suffered cold damage after a severe drop in temperature, halting the bloom immediately and causing the foliage to wither and tips to die. Source: Carter, S. 2007. Personal communication, May 17. Sarah Carter is the curator of Herbaceous Plants and Outdoor Gardens.

6 Daley, B. 2007. Winter warm-up costing N.E. region. *The Boston Globe*, January 28.

7 Caldwell, D. 2007. Winter? What winter? *The New York Times*, January 12.

8 NECIA 2006.

9 The Northeast states have already taken an early but promising step by formalizing the Regional Greenhouse Gas Initiative (RGGI)—the first multi-state effort in the nation to cap carbon emissions from electric power plants—and moving toward the creation of the nation's first carbon market. In addition, many states in the region have developed policies to promote energy efficiency and renewable energy, cleaner cars, and climate action plans, and to reduce emissions from state government operations.

10 While population growth in the Northeast is somewhat slower than the national average, the pace of development is quite high. Several Northeast states (NJ, RI, MA and CT, in order) topped the national list in the percentage of non-federal land that was developed in 1997. Pennsylvania and New York, meanwhile ranked 5th and 12th respectively for the total land area developed between 1992 and 1997. Source: National Resources Inventory. 2000. *Developed land "top ten" states*. United States Department of Agriculture (USDA), Natural Resources Conservation Services. Online at *http://www.nrcs.usda.gov/technical/land/tables/t5844.html.*

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12 Ibid.

13 Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: The Scientific Basis*, Summary for Policy Makers. Cambridge, UK: Cambridge University Press.

14 Intergovernmental Panel on Climate Change (IPCC). 2007b. *Climate Change 2007: The Scientific Basis*, Summary for Policy Makers. Cambridge, UK: Cambridge University Press. In press. Online at *http://www.ipcc.ch/SPM2feb07.pdf.*

15 For further discussion, see: IPCC 2007a. And: Hayhoe, K., C.P. Wake, B. Anderson, J. Bradbury, A. DeGaetano, A. Hertel, X.-Z. Liang, E. Maurer, D. Wuebbles, and J. Zhu. 2006. Quantifying the regional impacts of global climate change: Evaluating AOGCM simulations of past and future trends in temperature, precipitation, and atmospheric circulation in the northeast US. *Bulletin of*

the American Meteorological Society. In review. And: Hayhoe, K., C.P. Wake, T.G. Huntington, L. Luo, M. Schwartz, J. Sheffield, E. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T. Troy, and D. Wolfe. 2007. Past and future changes in climate and hydrological indicators in the U.S. Northeast. *Climate Dynamics* 28:381-407. And: Hayhoe, K., C.P. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A. Hertel, and D. Wuebbles. 2008. Regional climate change projections for the Northeast U.S. *Mitigation and Adaptation Strategies for Global Change*. In press. And: NECIA 2006.

16 For further discussion, see: Hayhoe et al. 2006. And: Hayhoe et al. 2007. And: Hayhoe et al. 2008.

17 Hayhoe et al. 2006.

18 Hayhoe et al. 2007.

19 Hayhoe et al. 2008.

20 NECIA 2006.

21 Results represent the average of the GFDL- and PCM-based model simulations.

22 Results represent the average of the HadCM3 and PCM-based model simulations.

23 Some well-monitored sites have experienced an average decrease in snowpack depth of 16 percent along with an 11 percent increase in snow density in March and April. Source: Hodgkins, G.A., and R.W. Dudley. 2006. Changes in late-winter snowpack depth, water equivalent, and density in Maine, 1926-2004. *Hydrological Processes* 20:741-751.

24 Results represent the average of the HadCM3 and PCM-based model simulations.

25 Six inches represents a linear extension of the average historical rate of global SLR of .07 inch per year (1.8 mm/yr), for the years 1961 to 2003. It should be noted that the observed rate of global SLR from 1993 and 2003 was .12 inch per year (3.1 mm/year). Source: IPCC 2007b.

26 IPCC 2007b.

27 Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315(5810):368-370.

28 To simulate changes in sea-level rise, NECIA researchers tuned the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC, *http://www.cgd.ucar.edu/cas/wigley/magicc/*) using different rates of ice melt and values for climate sensitivity to match the following four projections for end-of-century change:

(1) a linear extension of historical global SLR rates of 0.18 mm/yr (1961 to 2003 (IPCC 2007b)),

(2) the mid-range of the IPCC projections under the lower-emissions scenario (IPCC 2007b),

(3) the mid-range of the IPCC projections under the higher-emissions scenario (IPCC 2007b),

(4) the mid-range of a new set of projections (Rahmstorf 2007) under the higher-emissions scenario

IPCC (2007b) projections of SLR are for the period 2090-2099 relative to 1980-1999, while Rahmstorf (2007) projections are for 2100 relative to 1990. Observed SLR over the past 15 years was taken into account by subtracting SLR at the observed 1993-2003 rate of 3.1 mm/year (IPCC 2007b) for the period 1990-2005 from the IPCC and Rahmstorf end-of-century estimates, such that all future SLR projections were normalized to 2005. Sources: IPCC 2007b. And: Rahmstorf 2007.

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33 Payne, A., A. Vieli, A.P. Shepherd, D.J. Wingham, and E. Rignot. 2004. Recent dramatic thinning of largest West Antarctic ice stream triggered by oceans. *Geophysical Research Letters* 31(23).

34 NECIA 2006.

Chapter Two
COASTAL IMPACTS

1 This figure includes coastal counties from Maine through Virginia. Source: Crossett, K.M., T.J. Culliton, P.C. Wiley, and T.R. Goodspeed. 2004. *Population Trends Along the Coastal United States: 1980–2008*. Coastal Trends Report Series, National Oceanic and Atmospheric Administration (NOAA). Online at *http://oceanservice.noaa.gov/programs/mb/supp_cstl_population.html*.

2 Nationally, coastal property values doubled in the 10 years preceding 2004. The Northeast figure includes residential and commercial properties. Source: Insurance Information Institute. 2004. Value of insured coastal property vulnerable to hurricanes by state, 2004. Onlineat *http://www.iii.org/economics/state/catastrophes/*.

3 In 2004, 63% of all insured property in Connecticut is considered coastal; in New York, 61%; Maine, 58%; and Massachusetts, 54%. Source: Insurance Information Institute 2004.

4 According to recent research, the rate of relative sea-level rise in southern New England has increased three-fold over the past 150 years—timing consistent with the onset of global warming. Sources: Donnelly J.P., P. Cleary, P. Newby, and R. Ettinger. 2004. Coupling instrumental and geological records of sea-level change: Evidence from southern New England of an increase in the rate of sea-level rise in the late 19th century. *Geophysical Research Letters* 31(5). And: Donnelly, J.P. 2006. A revised late holocene sea-level record for northern Massachusetts, USA. *Journal of Coastal Research* 22(5):1051–1061.

5 According to available data from long-term Global Positioning System stations, areas in northern Maine, by contrast, actually show slight uplift (~1 mm/yr). Source: Evens, R. 2007. Personal communication, April 20. Rob Evans is an associate scientist in the geology and geophysics department at Woods Hole Oceanographic Institute (WHOI).

6 Six inches represents a linear extension of the average historical rate of global SLR of 0.18 mm/yr, for the years 1961 to 2003. The observed rate of global SLR from 1993 and 2003 was 3.1 mm/year. Source: Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: The Scientific Basis*, Summary for Policy Makers. Cambridge, UK: Cambridge University Press. In press. Online at *http://www.ipcc.ch/SPM2feb07.pdf*.

7 IPCC projections of SLR are for the period 2090-2099 relative to 1980-1999. Source: IPCC 2007a.

8 These projections are for 2100 relative to 1990. Source: Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315(5810):368-370.

9 Northeast Climate Impacts Assessment (NECIA). 2006. *Climate Change in the U.S. Northeast. A Report of the Northeast Climate Impacts Assessment*. Cambridge, Massachusetts: Union of Concerned Scientists.

10 While the coincidence of storm surge with high tide can increase the damage and loss of life, a storm surge event at low tide can still result in catastrophic damage. For example, the 1821 New York City hurricane hit at low tide and still resulted in a storm surge over three meters above mean high water. Source: Donnelly, J. 2007. Personal communication, May 2. Jeff Donnelly is an associate scientist at the Woods Hole Oceanographic Institute (WHOI).

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17 Donnelly et al. 2004.

18 Donnelly 2006.

19 Pielke and Landsea 1998.

20 Gornitz, V., and S. Couch. 2000. Coastal sector: Sea level rise and coastal hazards. In *Climate Change and a Global City: An Assessment of the Metropolitan East Coast Region*, edited by C. Rosenzweig and W.D. Solecki. 2001. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. New York: Columbia Earth Institute. Online at *http://metroeast_climate.ciesin.columbia.edu/reports/coasts.pdf*.

21 Ibid.

22 The New York City Office of Emergency Management, launched in 1996, put in place the first city-wide coastal storm management plan in 2000. The office has created hurricane evacuation zones for areas that are at high risk of coastal flooding, coordinated evacuation drills and established storm shelters. Several of its emergency storm shelters were opened during the April 2007 nor'easter. Source: City of New York, Office of Emergency Management (OEM). 2007a. Planning for emergencies: Coastal storm plan. Online at *http://home2.nyc.gov/html/oem/html/about/planning_coastal_storm.shtml*.

23 This was true for the legendary 1938 hurricane, during which an unexceptional storm surge combined with an anomalously high tide and dangerous wind-driven wave effects to cause catastrophic damage. The same was true of the coastal flooding associated with the infamous Blizzard of 1978; the storm surge was only moderately extreme but, combined with an extremely high tide and intense, wind-driven wave action, led to coastal damages totaling $550 million. On the other hand, the storm surge associated with the Perfect Storm of Halloween 1991, immortalized in book and movie, was one of the largest on record. The fact that this storm did not coincide with astronomically high tides likely spared the region far greater flood damage.

24 Kirshen, P., C. Watson, E. Douglas, A. Gontz, J. Lee, and Y. Tian. 2008. Coastal flooding in the northeastern United States due to climate change. *Mitigation and Adaptation Strategies for Global Change*. In press.

25 NECIA researchers projected both the change in recurrence intervals of today's 100-year coastal flooding event in the five locations, as well as the floodwater heights associated with future 100-year flood events, by mid- and late-century, using the following series of sea-level rise projections:

(1) a linear extension of historical global SLR rates of 0.18 mm/yr (1961 to 2003) (IPCC 2007a),

(2) the mid-range of the IPCC AR4 projections under the lower-emissions scenario (IPCC 2007a),

(3) the mid-range of the IPCC AR4 projections under the higher-emissions scenario (IPCC 2007a),

(4) the mid-range of a new set of projections (Rahmstorf 2007) under the higher-emissions scenario

Changes in sea-level rise were simulated by the MAGICC model, which was tuned using different rates of ice melt rates and values for climate sensitivity.

Sources: IPCC 2007a. And: Rahmstorf 2007.

26 All projected coastal flood elevations are relative to the North American Vertical Datum of 1988 (NAVD). In Boston, for example, NAVD is approximately four inches (~0.3 feet) above mean sea level. Projected coastal flood elevations also assume that the storm surge occurs during an average high tide (i.e., the long-term average of the highest daily tides).

27 The increased flooding frequencies in Boston and Atlantic City relative to the other three (New York City, New London, and Woods Hole) are likely due to differences in the physical location of the tide gauges at each site as well as the hydraulic influences measured during a coastal flooding event. In Boston and Atlantic City, the tide gauges are located such that only oceanic storm responses are measured during coastal flooding events. Sea-level rise, therefore, is the major factor influencing the projected increases in coastal flooding frequencies.

At the other three sites (New York City, New London, and Woods Hole) oceanic storm surges are not the only measured component of coastal flooding. Rain associated with coastal storms generates a large volume of fresh water flowing in the Hudson River in New York, and the Thames River in New London. Because of their location at the mouths of these major rivers, the tide gauges measure the combination of storm surge and increased river flow during coastal flooding events. In Woods Hole, the strong and complex tides and currents, from which the "Hole" gets its name, likely has a strong influence on the water

levels measured during coastal flooding events. Thus, in these three cases, oceanic storm surges are not the only factor in coastal flooding; increases in sea level have a relatively smaller direct influence on the associated increases in coastal flooding frequencies than in the other locations. In addition, during the NECIA analysis, statistically significant trends in the coastal flood event time series were identified at both Boston and Atlantic City. The presence of these trends required additional analysis and affected the shape of the frequency curves relative to the other three sites.

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29 The Boston inundation maps were created using data available from Commonwealth of Massachusetts Executive Office of Environmental Affairs' Office of Geographic and Environmental Information (MassGIS). The blue shading is shown over aerial photographs for reference. The future areas of flooding (shown in light blue) are based on a digital elevation model (DEM) derived from LIDAR (an acronym for Light Detection and Ranging) data obtained by MassGIS in 2002.

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31 Ibid.

32 The Boston maps show flooding in the general area of the Interstate 93 tunnel entrances, but do not include actual elevations of these entrances, and cannot therefore project changing risk of flooding in the tunnel as a result of greater coastal flooding events.

33 Estes-Smargiassi, S. 2007. Personal communication, May 30. Stephen Estes-Smargiassi is the Director of Planning at the Massachusetts Water Resources Authority (MWRA).

34 All figures are in 2000 dollars, with no discounting. Source: Kirshen, P., M. Ruth, and W. Anderson. 2006. Climate's long-term impacts on urban infrastructures and services: The case of Metro Boston, Chapter 7. In *Climate Change and Variability: Local Impacts and Responses*, edited by M. Ruth., K. Donaghy, and P.H. Kirshen. Cheltenham, England: Edward Elgar Publishers.

35 For the lower SLR scenario, the CLIMB analysis relied upon the Canadian Climate Center's GCM1 model output, which projected .41 meter SLR by 2100. For the higher scenario, 1 meter of SLR by the end of the century was assumed. Source: Kirshen et al. 2006.

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Chapter Three
MARINE IMPACTS

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15 Figures presented here represent the mid-range of the 3-model outputs, for each scenario. In the NECIA marine analysis, both the historic and the late-century projected time frames vary from other NECIA analyses, reflecting both National Marine Fisheries Service historic data sets and model capabilities.

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Chapter Four
IMPACTS ON FORESTS

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WATER: A VITAL RESOURCE

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Chapter Five
IMPACTS ON AGRICULTURE

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monly grown cultivars but no low-chill varieties. Source: DeMoranville, C. 2007. Personal communication, May 29. Carolyn DeMoranville is the director of the University of Massachusetts Cranberry Station.

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22 DeMoranville 2007.

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Chapter Six
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17 Snowmobile sites assessed include:

1. Eastern Pennsylvania
2. South-central Pennsylvania
3. North-central Pennsylvania
4. Western New York
5. North-central New York
6. North Country New York
7. Southeast New York
8. Western Massachusetts
9. Northern Vermont
10. Southern Vermont
11. Southern New Hampshire
12. Northern New Hampshire
13. Southern Maine
14. Northwest Maine
15. Down East Maine

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Chapter Seven
IMPACTS ON HUMAN HEALTH

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Chapter Eight
MEETING THE CLIMATE CHALLENGE

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UCS combines independent scientific research and citizen action to develop innovative, practical solutions and to secure responsible changes in government policy, corporate practices, and consumer choices.

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