MAINE'S CLIMATE FUTURE

An Initial Assessment

February 2009
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1865 THE UNIVERSITY OF MAINE

Maine's Climate Future:
An Initial Assessment

Acknowledgements
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SUMMARY

Earth's atmosphere is experiencing unprecedented changes that are modifying global climate. Discussions continue around the world, the nation, and in Maine on how to reduce and eventually eliminate emissions of carbon dioxide (CO_2), other greenhouse gases, and other pollutants to the atmosphere, land, and oceans. These efforts are vitally important and urgent. However, even if a coordinated response succeeds in eliminating excess greenhouse gas emissions by the end of the century, something that appears highly unlikely today, climate change will continue, because the elevated levels of CO_2 can persist in the atmosphere for thousands of years to come.

In late 2007, Governor Baldacci asked the University of Maine and its Climate Change Institute to lead a preliminary analysis of the effects of climate change in Maine during the 21st century. This report considers past climate change, recent evidence of accelerated rates of change, and the implications of continued climate change in Maine as a result of greenhouse gas emissions and their associated pollutants. The report also highlights examples of adaptation challenges, and emphasizes new opportunities that exist in an era of climate change. Participating scientists volunteered their time and expertise to initiate a process that can both inform and facilitate systematic planning and thoughtful decisions for climate change challenges facing Maine.

Perhaps more than any other state, our social and economic well-being depends on the health and productivity of Maine's forests, fields, lakes, rivers, and the marine waters of the Gulf of Maine. The diversity of these natural systems and the plants and animals within them result from the wide range of geologic, topographic, and climatic conditions present in the state. Although many states have a wide variety of environments, few have anything approaching Maine's range of climates in close proximity. Our unique diversity of climates means that change will not be uniform across the state; indeed we are already witnessing different responses in northern Maine compared to southern and coastal regions.

For the past century, the *rate* of warming in Maine has been increasing. All three of Maine's climate divisions are warmer today than 30 years ago. Regional sea surface temperatures have increased almost 2° Fahrenheit since 1970, and the rate of sea-level rise has intensified. Tide-gauge records in Portland, Maine, show a local relative sea-level rise of approximately eight inches since 1912. The seasonality of events is also shifting, especially in winter and spring, with earlier snowmelt, peak river flows, and ice-out on Maine lakes.

To predict what further changes we can expect over the next century, we used simulations of climate change under an assumed intermediate level of greenhouse gas emissions (a mid-range scenario from the recently completed UN Fourth Assessment of the Intergovernmental Panel on Climate Change). The results of this assessment can be used to discern the *direction* and *range* of likely changes in temperature and precipitation, and the relative variation among climate zones in Maine.

For the 21st century, the models show a strong trend in Maine toward warmer conditions with more precipitation in all four seasons. A warmer and wetter future will affect the seasons as we know them, with more winter precipitation in the form of rain and a continued shift in the timing of hydrological events, such as spring runoff. Other assessments forecast increased intensity of precipitation, as suggested by several recent severe storm events. A warmer ocean could increase the frequency and intensity of hurricanes, with implications for water and wastewater management, coastal infrastructure, and water quality.

Climate change will almost certainly lead to significant changes in Maine's overall assemblage of plants and animals, including those living in our coastal waters. It is difficult to predict effects on specific species, but we may have fewer spruce, loons, chickadees, lynx, halibut, and moose; and more oaks, bobcat, summer flounder, and deer. The state list of endangered and threatened species will likely grow as a result of climate change. In the Gulf of Maine, warm temperatures will restrict habitat for certain commercially important species such as cod. Fishermen are already noticing significant changes in the lobster fishery, including altered growth and migration behavior. At the same time, economically important fish species from the south may become more common in Maine.

Climate change is not simply the physical changes in temperature and precipitation. Rather, it occurs within a complex realm of environmental interactions, often with unpredictable results. For example, potential increases in commercially important fish or tree species could be tempered by simultaneous increases in toxic red tides, invasive species, pests, or diseases. Climate change includes, for example, the direct "fertilizing" effects of rising atmospheric CO_2 and nitrogen deposition on forests and agricultural crops, making them grow faster. Oceans not only warm and expand, but they also absorb excess CO_2, which makes them more acidic.

The forest industry can expect continued forest cover in Maine, with shifting geography for individual tree species, as balsam fir and spruce give way to red maples and other hardwoods. Climate change also may affect overall wood availability and will certainly change the timing of forest operations. A longer mud season and shorter periods of hard freeze could restrict the traditional winter harvesting season. The forest industry and other sectors will be strongly influenced by climate change effects on resources and markets outside of Maine.

As the assemblages of plants and animals change, resource managers, landscape planners, and conservationists can expect an increase in those species that spread easily, are adapted to a variety of conditions, and reproduce rapidly—all characteristics of weedy or invasive species.

Farmers might experience greater risk of yield reductions due to drought, new pests, and weeds. Access to water for irrigation is becoming more important with increasing drought stress later in the growing season, as the growing season becomes warmer and longer. However, with adequate preparation, farmers will also have access to a new and broader range of crops to serve a population increasingly interested in locally produced food. The latter trend will be especially important as Maine strives to become more energy-efficient and self-sustainable.

Maine's growing tourism economy, which relies heavily on outdoor activities, must prepare for shorter ice-fishing, skating, skiing, and snowmobiling seasons, while simultaneously anticipating more visitors during longer "shoulder" seasons in spring and fall. Tourism attractions and activities associated with our cultural and natural heritage may be diminished by the potential loss of moose, trout, and brown ash trees from certain areas of the state.

Transportation planners are already considering climate change when assessing new construction projects, but a more comprehensive assessment of the vulnerability of our roads, bridges, dams, wastewater treatment plants, and other infrastructure is warranted.

Opportunities exist today to design structures with the capacity for future conditions. One important near-term priority should be to review engineering standards, taking into account the implications of climate change.

The mechanisms of climate change impacts on human health are difficult to forecast with confidence. Increasing temperatures will change the distribution of disease-bearing insects and pathogens. For example, Lyme disease is carried by the deer tick associated with populations of deer and white-footed mice in deciduous forests. All signs suggest northward spread of those conditions and cases of Lyme disease are on the rise in Maine. Maine's statewide public health system is still relatively new, and it will need to grow quickly and be flexible in order to define and address new and emerging health threats related to a changing climate.

The Wabanaki peoples of Maine, like many other residents of the state, depend heavily on agriculture, forest products, and tourism. The Wabanaki are spiritually and culturally invested in specific areas of Maine, and many of their values, meanings, and identities are closely linked with the natural landscape and physical interactions with that landscape. Tribal members tend to have close affinity with natural ecosystems, and the projected changes in biodiversity are likely to present adaptive challenges to the communities involved. Potential ecosystem responses to climate change may alter livelihoods and traditions of indigenous peoples in Maine, and may require special monitoring of health and economic effects. The vitality of Maine's indigenous peoples may very well depend on their abilities to help shape new economies and sustainable development, including decisions on natural resource management.

Reducing human and ecosystem vulnerability to harm and increasing resilience in the face of change is both an economic and a moral imperative. From our first greenhouse gas emissions inventory in 1995 to the nation's first statewide climate change law in 2003, Maine has been a leader in addressing climate change and reducing greenhouse gas emissions. These important mitigation efforts must continue. Maine also needs an adaptation plan that includes the development of new opportunities that will be available in a changing climate.

A climate adaptation plan for Maine would first assess the vulnerability of natural and built systems, as well as the costs and benefits of action versus inaction. Evaluating vulnerabilities will reveal opportunities. Second, an adaptation plan would evaluate local adaptive capacity (*i.e.,* is current policy or infrastructure ignoring, combating, or promoting change?). This would include the range of technical options, the availability and equitability of resources, the structure and functionality of critical institutions, and human and social capital.

Assessments of the consequences of climate change tend to focus on the negative because of the obvious difficulties and costs of change in our society. In this report, we have tried to highlight some of the critical challenges faced during this period of transition in various ecosystems and economic sectors in Maine. This information is intended to help frame the policy and management discussions on adaptation that are urgently needed. In addition, however, we have emphasized the idea that this period of transition is a unique time of opportunity. Maine can lead the nation by making the 21st century transition a positive one.

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1 STATE HOUSE STATION
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JOHN ELIAS BALDACCI
GOVERNOR

November 8, 2007

Professor Paul A. Mayewski, Director
Climate Change Institute
University of Maine
133 Sawyer Environmental Research Center
Orono, ME 04469

Re: Maine Climate Change Assessment

Dear Dr. Mayewski:

These are times of unusually dynamic policy development as we face the pressing issues of complex projections for the chemical and physical climate in the 21st century. It is essential to Maine's future that we undertake management and policy decisions with the best available scientific information. To accomplish this, policymakers must have access to and benefit from the work of the scientific research community.

The University of Maine has served as the flagship land grant and natural resource institution for Maine for over 140 years and is the home of the Climate Change Institute and a cadre of specialized centers and programs. The University represents the resources needed to provide the scientific and technical information Maine needs to mitigate, adapt, and capitalize on new opportunities in a changing climate. I thank the University's Climate Change Institute for your offer to undertake a Maine Climate Change Assessment.

For these reasons, I request the University of Maine to prepare a report during the next twelve months that accomplishes the following:

- Identifies the potential climate scenarios, and their probabilities, for Maine for the remainder of the 21st century;
- Inventories the critical impacts, adaptations, and opportunities represented by these scenarios;
- Identifies critical environmental monitoring, research and assessment needs on this issue; and
- Defines a framework to continue an ongoing effective dialogue for science to inform policy on issues of our chemical and physical climate in Maine.

In conducting this work, I appreciate that you will reach out to other educational and research institutions and organizations who are conducting research on Climate change.

I thank you in advance for this extremely important project that may well have significant and direct bearing on the future economic prosperity, quality of life and safety of Maine's residents. If you need assistance, please contact Karin Tilberg, Senior Policy Advisor, at my office.

Sincerely,

John E. Baldacci
Governor

cc: Karin R. Tilberg, Governor's Office
John Kerry, Director Office of Energy Independence and Security
Dave Littell, Commissioner Department of Environmental Protection
Patrick K. McGowan, Commissioner Department of Conservation
George Lapointe, Commissioner Department of Marine Resources
Seth Bradstreet, Commissioner Department of Agriculture
Dr. George L. Jacobson Jr., Professor of Quaternary Biology, Orono
Dr. Ivan Fernandez, Professor of Soil Science, Orono
President Robert Kennedy, University of Maine

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INTRODUCTION

The Earth's atmosphere is experiencing unprecedented changes that are modifying the global climate, with consequences for all regions and societies. Discussions have begun on how to reduce and eventually eliminate the rapid and accelerating additions of carbon dioxide, other greenhouse gases, and other pollutants to the world's atmosphere and oceans. *These efforts are vitally important and urgent for Maine and the rest of the world.*

This report considers past change over geologic time, recent evidence of accelerated rates of change, and the implications of continued climate change in Maine during the 21st century as a result of greenhouse gas emissions and their associated pollutants. Even if a coordinated response succeeds in *eliminating* excess greenhouse gas emissions by the end of the century, something that appears highly unlikely today, climate change will continue because the elevated levels of carbon dioxide (CO_2) can persist in the atmosphere for thousands of years to come.

About this report

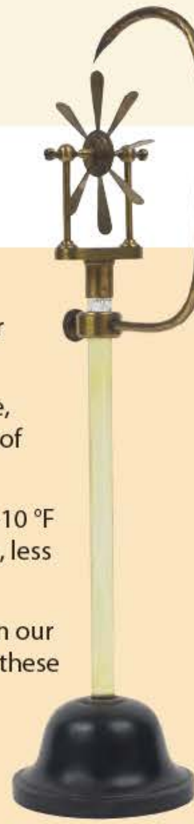
In late 2007, Governor Baldacci asked the University of Maine and its Climate Change Institute to lead a wide-ranging analysis of the state's future in the context of changing climate during the 21st century. The assignment involved making use of existing knowledge and understanding of climate change; the terrestrial, freshwater, and marine ecosystems that characterize our environment; and the socioeconomic characteristics of the state. The project involved no financial support for new research or data collection, but participating scientists contributed their time and expertise to initiate a process that could lead to systematic planning and thoughtful decisions for the future. Based on considerable prior research, this report serves as a preliminary step designed to frame future detailed analyses focused on Maine by teams that will likely continue for years.

Why should this evaluation focus specifically on Maine? Several well-known useful assessments have been published in recent years, each addressing the implications of the climate changes likely to result from the steep increases in atmospheric concentrations of greenhouse gases. The Intergovernmental Panel on Climate Change (IPCC 2007a,b) report provides an updated, comprehensive global view of the issues, and readers are well served by the reliable and well documented information therein. The US Climate Change Program issued a national and regional overview (NERAG 2001), and the Union of Concerned Scientists recently released a regional Northeast Climate Impacts Assessment (Frumhoff *et al.* 2006). None have focused on the unique character of Maine.

Maine has some characteristics that deserve particular attention and analysis. Perhaps more than any other state, our social and economic well-being depends on the health and productivity of Maine's forests, fields, lakes, rivers, and the marine waters of the Gulf of Maine. The diversity of these natural systems results from the wide range of geologic, topographic, and climatic conditions present in the state. Although many regions of the world have a variety of environments, few have such variety in close proximity. In fact, the primary reason for such high biodiversity in Maine is the extreme range in climates within a relatively small area. While the southern coast generally remains relatively mild, even in winter, northern Aroostook County has some of the coldest weather in the coterminous US. Maine's character and complexity can be expected to offer unique challenges and opportunities as a result of a changing climate. This report is distinctly about Maine.

G Shriver

Maine's Climate Yesterday, Today, And Tomorrow



Team Leader George Jacobson
Authors Ivan Fernandez,[1] George Jacobson,[2] Shaleen Jain,[3] Kirk Maasch,[4] Paul Mayewski,[4] and Stephen Norton[4]

Maine's unique and wide range of climates and landscapes from the mountains to the sea is an important consideration when assessing and addressing climate change here, compared to the rest of New England or the world.

Since 1970, the northeastern US has experienced a 0.45°F (0.25°C) average temperature increase per decade, and the surface temperature of Maine's coastal waters has increased almost 2°F (1.1°C). An accelerated rate of climate change is highly likely to continue in the 21st century.

Depending on future emissions scenarios, changes in the region's climate over the next century include a 3-10 °F (2-6 °C) increase in average annual temperature, a longer growing season, a 2-14 % increase in precipitation, less snow, more rain, and highly variable precipitation.

Integrated with changes in the physical climate (*i.e.*, temperature and moisture) are simultaneous changes in our chemical climate (*i.e.*, CO_2, sulfur, nitrogen, ozone, metals, and persistent organic pollutants). While some of these substances occur naturally in our environment, their concentrations have increased as a result of human activities, with maximum pollution of some metals and sulfur occurring in the 1970s. Concentrations of greenhouse gases continue to increase.

Since the late 1970s, atmospheric deposition of sulfur (mostly as sulfate), cadmium, mercury, and lead has declined significantly. Despite some evidence for recent reversals of these trends, the declines in pollution achieved at the end of the 20th century demonstrate our ability to make improvements in the environment by timely and committed action. More work needs to be done. The most urgent need is to reduce greenhouse gas emissions on a global scale. Maine's Climate Action Plan is an important step in this direction.

Weather vs. Climate

There's an old saying that "climate is what you expect, weather is what you get." *Weather* is the state of the atmosphere in terms of hot or cold, wet or dry, windy or calm, cloudy or clear. Instantaneous, or synoptic, measurements of meteorological variables—namely temperature, precipitation, humidity, pressure, winds, and cloudiness—are used to quantify the weather. These variables are often shown on a map or chart at a given time for a particular region.

Climate is the statistical collection of average weather conditions at a given place, typically defined over a 30-year time interval (or "normal"). At present, "normal" refers to the 1971-2000 average for a particular variable. Note that the climate defined using different periods of time may be different (e.g., the normals defined by the 1931-1960 average are different from those of 1961-1990); spatial scale also affects the definition of normals. Long-term climate is usually defined as a time average of a century or more.

Maine's instrumental record of meteorological variables has been systematically kept for about 130 years, although measurement stations are not distributed uniformly in time or space. It is from this instrumental record that climate variables can be calculated and examined in terms of any systematic climatic change that may have occurred. For the purposes of this discussion, we restrict ourselves to temperature and precipitation as diagnostics of climate and climate change.

1 Plant, Soil, & Environmental Sciences, University of Maine. 2 School of Biology and Ecology and Climate Change Institute, University of Maine. 3 Civil and Environmental Engineering and Climate Change Institute, University of Maine. 4 Earth Sciences and Climate Change Institute, University of Maine.

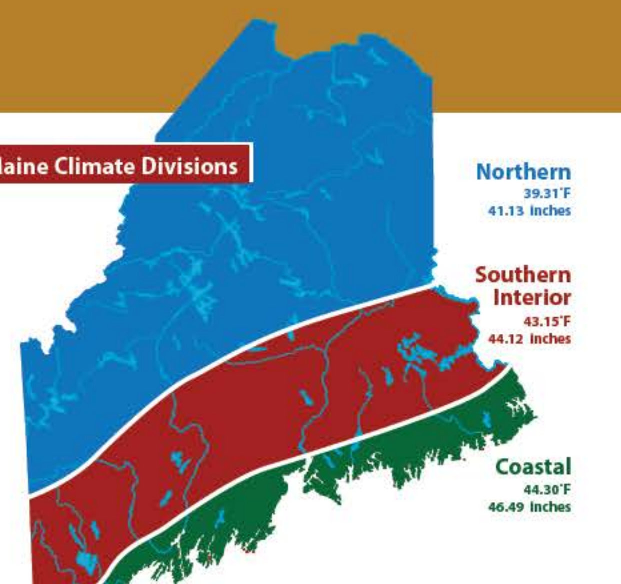


Figure 2 Long-term average temperature (°F) and precipitation (inches) for the three climate divisions in Maine, based on data from NOAA's National Climatic Data Center for the period of record 1895 through 2007. These climate divisions span 54%, 31%, and 15% of the state's total area, respectively. See Appendix for details.

Climate past

Maine's climate has changed continuously in the past, and will continue to do so in the future. For at least the past million years, growing and melting ice sheets have covered the state and then retreated, making distinct changes on the land. The smoothed mountains and hills, the scratched rock surfaces, the stones carried from far away, and the flat sand plains of blueberry barrens all resulted from the large glaciers that once covered Maine. *The Ice Age Trail* in eastern Maine now guides visitors through many of these interesting features (CCI 2006).

Maine was still completely covered by ice as recently as 15,000 years ago. Yet, in just 4,000 years, the ice was gone and most of our current forest tree species were present. That rapid transition from ice-age conditions to warmer "interglacial" climate was characteristic of the end of many of the recent ice ages. The first Native Americans who entered this area around 12,000 years ago almost certainly walked on the last remnants of the huge Laurentide ice sheet that once extended from the Canadian arctic across the Gulf of Maine.

Yet even during the past 11,000 years of warm, ice-free conditions, the climate changed continuously. For example, the first half of that period had warmer, drier summers than today and probably colder winters. These conditions strongly affected the forests, lakes, and rivers of the region, and forest fires were common in the summer.

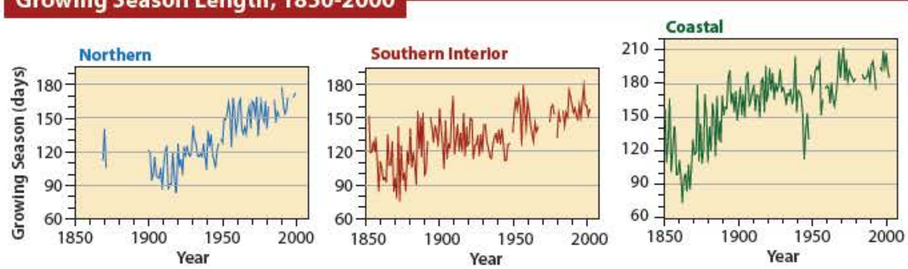


Figure 1 Growing season length in days for each climate division in Maine, based on data from Baron and Smith (1996) and NEISA (2005). Growing seasons were at times much shorter than present, with later frosts in the spring and earlier frosts in the fall.

During the last 4,000 years, Maine's climate gradually became cooler and moister. These changes influenced forest growth, and must have provided challenges to the long-established Wabanaki people, as well as to European settlers. Written records from the past few hundred years, including diaries kept by early farmers in Maine, provide clear evidence that the growing seasons were at times much shorter than present, with later frosts in the spring and earlier frosts in the fall (*Figure 1*; Baron and Smith 1996, NEISA 2005).

Climate present

Today, Maine has a wide variety of climates, a fact that is easy to take for granted. Although the National Weather Service divides the state into three climate divisions (*Figure 2*), the actual diversity of climate is much greater, and accounts for the wide variety of plants and animals in Maine. Maine's present-day climate can be quantified by looking at year-to-year variations of monthly (seasonal or annual) average temperature and precipitation in each of the three climate divisions (*Figures 2 and 3*). Although climate division data provide only a broad view of the climatic variations within the state, they are the benchmark often used to monitor and assess long-term changes.

Statewide, the warmest month is July and the coldest month is January. But viewed seasonally, monthly average high and low temperatures from south to north vary considerably. In the summer (May-August), the Southern Interior division is warmer than both the Northern and Coastal divisions. The waters of the Gulf of Maine moderate both summer and winter temperatures along the coastal zone, keeping the Coastal division relatively mild for the remainder of the year. In contrast, the interior of northern Aroostook County experiences warm summers *and* some of the coldest temperatures and highest snowfalls in the eastern US. The average annual frost-free period shrinks from close to 200 days in the south to around 160 days in the north.

Long-term average monthly precipitation is evenly distributed throughout the entire year, with slight differences between divisions. Monthly precipitation across the state averages between 2.9 and 3.9 inches for all 12 months. The coast is wettest in winter, while in the north summer is slightly wetter than winter. It is worth noting that the evenness of monthly precipitation in Maine is highly unusual globally; most places have high variability in moisture from season to season.

A comparison that illustrates Maine's extraordinary range in climate is presented in Figure 4. The climate gradient that exists in just three degrees of latitude in Maine occurs over 20 degrees of latitude in Europe, a distance approximately twice the length of California. The sharp contrasts in climate across our state mean that we have a much greater range in environments than is the case in most similarly-sized regions of the world. This is one of the reasons that Maine citizens and visitors find the area so appealing. It is also the reason that so many plants and animals reach the northern or southern edge of their range in Maine (see Biodiversity section, *Figure 18*) as well as in Maine's marine waters. The great variety of climates and environments in Maine also makes the challenges and opportunities we face in a changing climate both diverse and complex.

Changes over the 19th and 20th centuries

The rise of the Industrial Revolution at the end of 18th century led to major advances in agriculture, manufacturing, and transportation, as well as exponential growth in the world's population and resource consumption (*i.e.*, mining activities and the burning of wood, coal, oil, and natural gas). As a result, the Industrial Revolution marks the period during which humans began to substantially alter the composition of the atmosphere.

The influence of increased fossil fuel burning and other practices that release pollutants into the atmosphere rapidly accelerated during the 20th century, and is revealed in paleoclimatic records (*i.e.*, ice cores) and direct measurements of atmospheric chemicals (*Figure 5*). Increased levels of greenhouse gases and sulfate in the atmosphere affect Earth's energy balance and thus contribute to the observed changes in globally-averaged near-surface temperature (*Figure 6*).

While the overall trend of global temperature since 1850 has been one of warming, it has not been monotonic. Global temperature trends have increased over time as shown in Figure 6. The same is true for temperature trends in Maine (*Figure 7*). The US Global Change Research Program's New England Regional Overview (NERAG 2001) indicated that Maine had cooled over the period from 1885-1999 (and the global cooling between the 1940s and 1970s is evident in records from Maine). However, for this analysis we completed a closer examination of temperature trends for the length of record for each climate division, as well as for more recent time spans.

Our evaluation reveals that for the past century the *rate* of warming in Maine has been increasing (*Figure 7*). Today, all three of Maine's climate divisions are warmer than they were 30 years ago (a trend also experienced on a global scale, mostly because atmospheric pollutants like sulfate that produce acid rain and block solar radiation have been cleaned up; see box, "Maine's Chemical Climate" next page). These changes have affected growing conditions (*Figure 1*), and the horticultural plant hardiness zones for Maine have shifted by one zone to the north (see Agriculture, *Figure 20*).

The hydrologic cycle has also changed significantly over the last century (*Figure 8*). Although both the Northern and Southern Interior divisions show a negative trend in annual precipitation for the entire period of record, all three climate divisions have trended toward wetter conditions over the time span from 1950-2007.

Monthly Climate Conditions

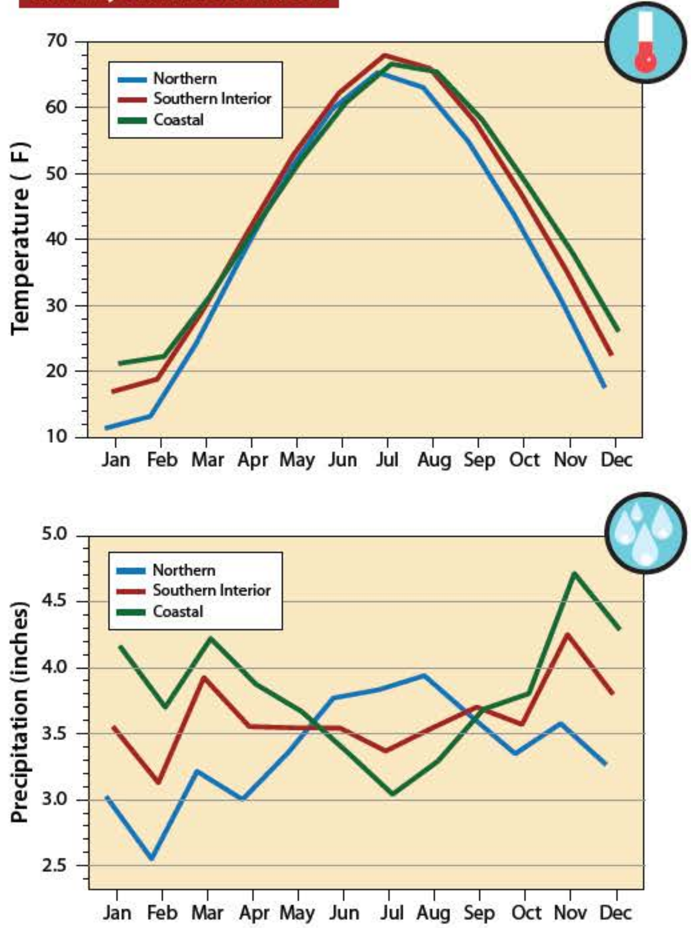


Figure 3 Linear trends in temperature and precipitation for the 1895-2007 period were computed based on area-averaged monthly data for the three climate divisions. See Append x for details.

Maine's Extraordinary Range in Climate

Figure 4 The climate gradient that exists in just three degrees of latitude in Maine occurs over 20 degrees of latitude in Europe, a distance approximately twice the length of California. Figure by K. Maasch.

Human Influence on the Global Atmosphere

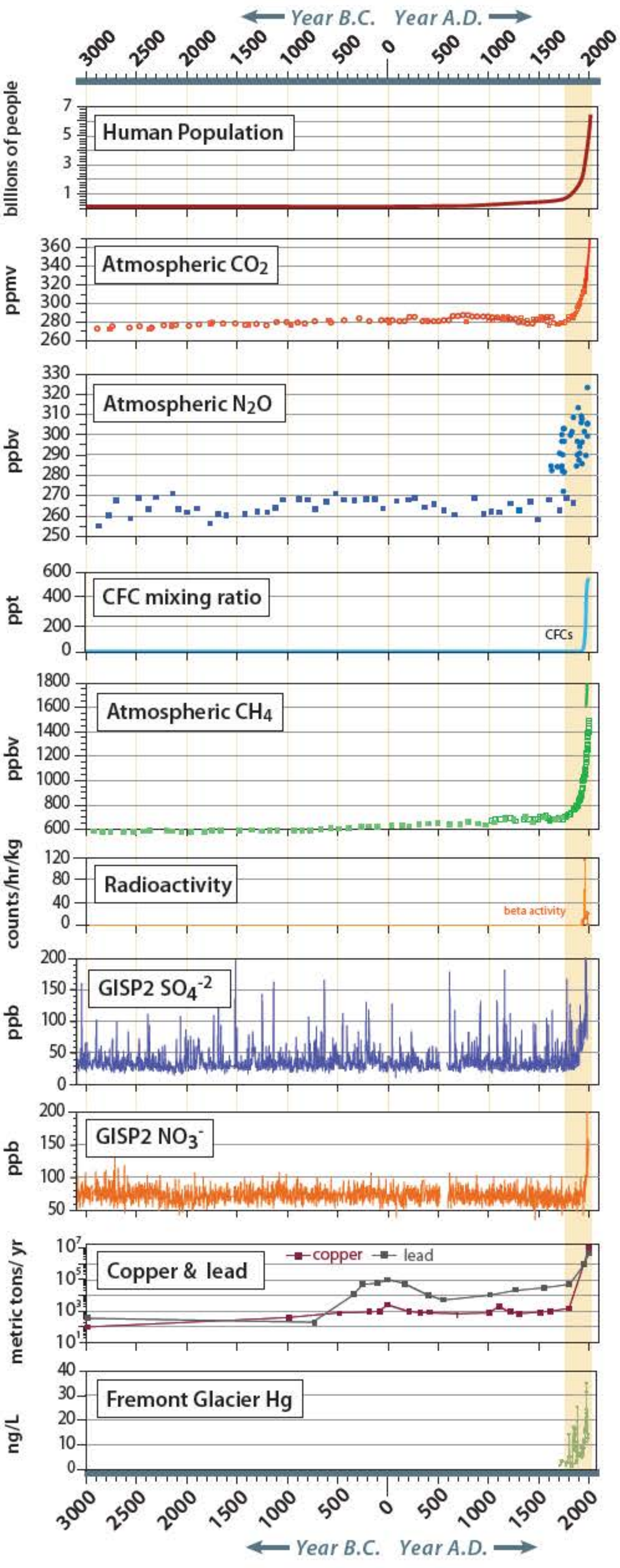


Figure 5 The panels show population (top) and concentrations of various chemicals in the atmosphere over the last 5,000 years. Paleoclimate records (*i.e.*, ice cores) and observations of large rises in atmospheric concentrations of greenhouse gases, chlorofluorocarbons, radioactive material (*e.g.*, beta activity from atomic bomb testing), sulfate and nitrate (precursors of acid rain), and trace metals reveal the influence of human activities, especially in the last 100 years. Data sources: Blunier *et al.* 1995; Chappallez *et al.* 1997; ESRL 2008 (*http://www.cmdl noaa.gov/ozwv/dobson/select.htm l*); Etheridge *et al.* 1994, 1996, 1998; Hong *et al.* 1994, 1996; Hou *et al.* 2002; Indermühle *et al.* 1999; Kang *et al.* 2001, 2002a, 2002b; Leuenberger and Siegenthaler 1994; Mayewski *et al.* 1986, 1990; Petit *et al.* 1999; Qin *et al.* 2002; Sato *et al.* 2007 (*http://www.giss.nasa.gov/data/simodel/ghgases/*); Schuster *et al.* 2002; Stauffer *et al.* 1998.

Global Temperature, 1850-2005

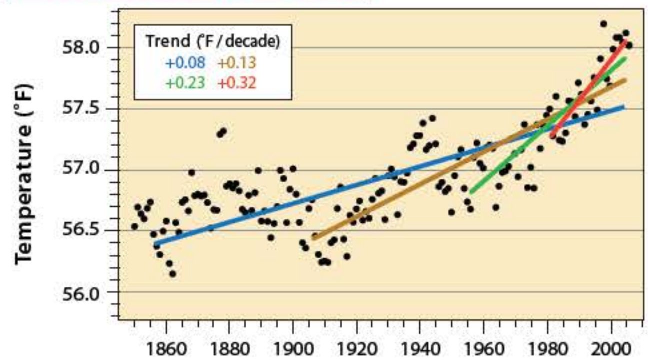


Figure 6 Global annual average temperature from 1850-2005 (black dots) along with simple fits to the data (IPCC 2007a). Linear trend fits to the last 25 (red), 50 (green), 100 (brown), and 150 (blue) years correspond to 1981 to 2005, 1956 to 2005, 1906 to 2005, and 1856 to 2005, respectively. For shorter, more recent periods, the rate of temperature increase is greater, indicating accelerated warming.

Maine's Chemical Climate

Climate change consists of physical changes in our environment as well as chemical changes in Earth's atmosphere. The increases in carbon dioxide (CO_2) and other greenhouse gases that are associated with warmer temperatures and altered precipitation occur in an atmosphere that contains other chemicals (some of which occur naturally in our environment, such as the trace metals cadmium, mercury, and lead). Many of these other chemicals can be harmful to humans and other living things. Concentrations of these and other substances also have increased as a result of human activities, with maximum pollution in North America occurring about 1970.

The recent history of human influence on concentrations of chemicals other than CO_2 illustrates how appropriate policy and management actions can be effective at reducing atmospheric pollution. Between 1970 and 2000, atmospheric deposition of sulfur (mostly in the form of sulfate), cadmium,

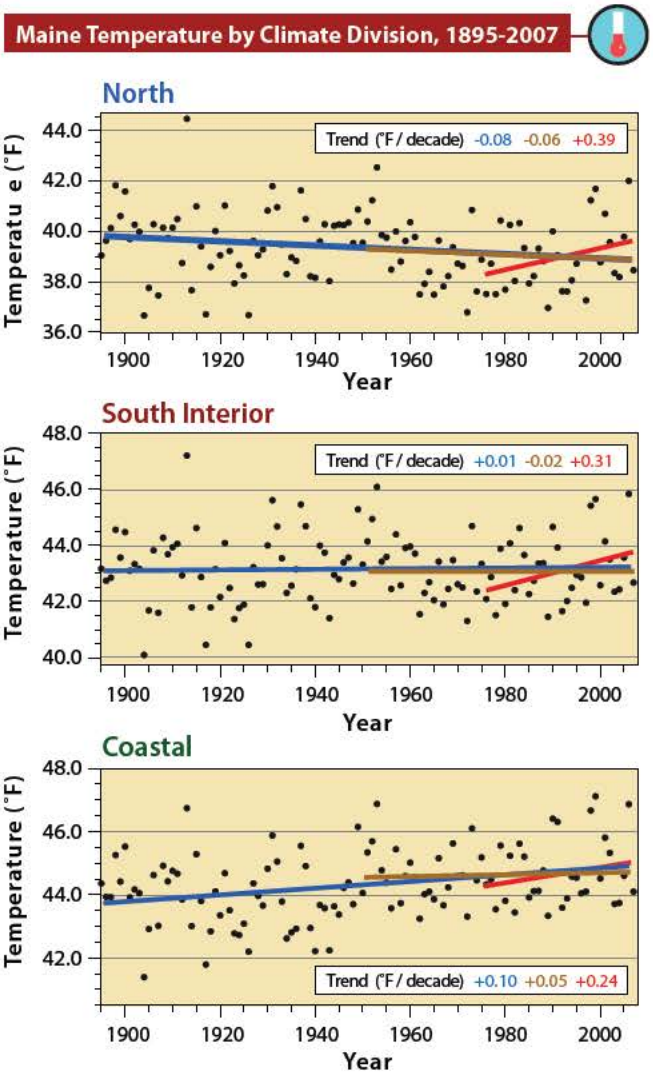


Figure 7 Annual average temperature for each climate division, 1895-2007 (black dots). Linear trends since 1895 (brown), 1975 (red), and 1950 (green), computed based on area-averaged monthly data for the three climate divisions, show the increasing rate of warming in the last three decades. See Appendix for details.

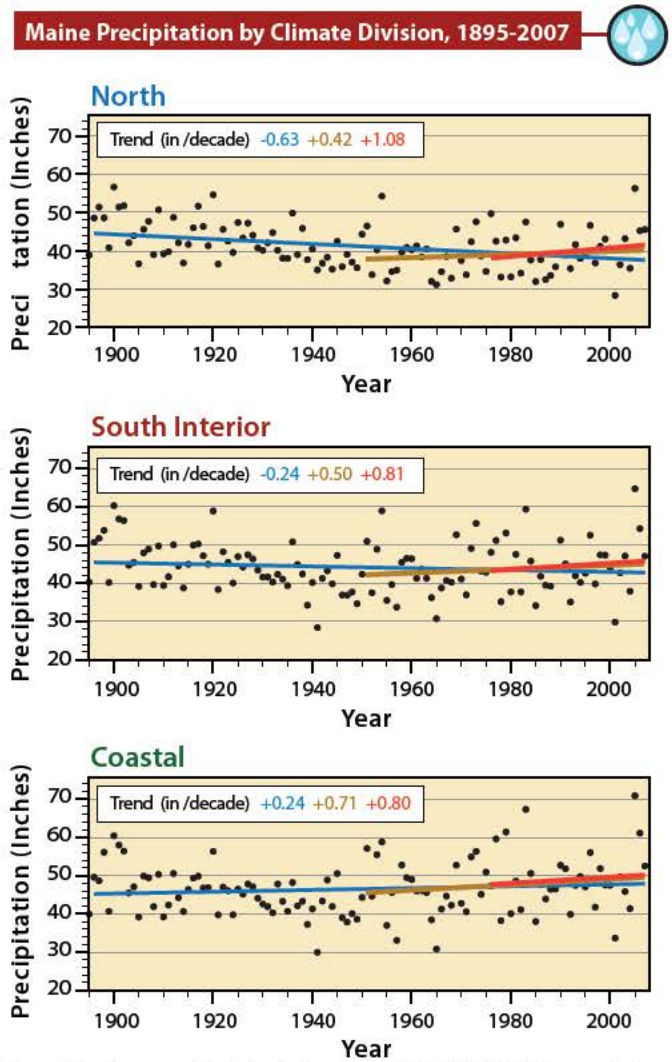


Figure 8 Annual average precipitation for each climate division, 1895-2007 (black dots). Linear trends since 1895 (brown), 1975 (red), and 1950 (green), computed based on area-averaged monthly data for the three climate divisions. All three climate divisions have trended toward wetter conditions since 1950. See Appendix for details.

mercury, and lead declined more than 50%, 75%, 75%, and 95%, respectively. The Clean Air Act (1970) and subsequent Amendments (1990) that resulted in declines in the emission and deposition of certain chemicals have produced a cleaner atmosphere, and a recovering environment. However, elevated levels of other chemicals such as ground-based ozone, organic acids, and some trace elements still pose major concerns.

What goes up must come down, and atmospheric chemicals eventually fall back to Earth as dust, rain, and snow, and wash into rivers and lakes. By this process, air pollution becomes water pollution, as surface water reflects chemical changes in the atmosphere. Layers of peat in Caribou Bog (Orono, ME) and sediment in Sargent Mountain Pond (Mount Desert, ME) show the long-term presence of mercury in our environment, the pronounced increase as a result of human activity, and recent declines due to policy and regulation (Roos-Barraclough *et al.* 2006, Norton unpublished). Ice core records show a recent one-third decline in sulfate, the principal cause of acid rain in the northeastern US. Similarly, removal of lead from gasoline caused a dramatic reduction in deposition of lead from the atmosphere.

Human influences can rival the effects of the sun and volcanoes. Sulfate and other chemicals that go into the air along with CO_2 shield the Earth from incoming radiation, so some forms of pollution offset heating caused by greenhouse gases. (This cooling or "global dimming" effect can also result from forest fires and dust). As a result, temperature increases have lagged behind increases in CO_2 and other greenhouse gases. Another cause for the lag is the enormous capacity of the ocean to absorb CO_2 and hold heat. Since 1957 when direct measurements of atmospheric CO_2 began, the oceans have absorbed 22 times as much heat as the atmosphere (Levitus *et al.* 2005), although recent research suggests that this capacity may have been reached (Le Quéré *et al*. 2007).


D.J. Fernandez

"Prediction is very difficult, especially about the future."
—Physicist Neils Bohr

Climate future

In this report, climate simulations from a number of coupled ocean-atmospheric models are analyzed. We used simulations of 21st century climate change forced by scenario A1B (which assumes an intermediate level of greenhouse gas emissions; Meehl *et al.* 2007) from the recently completed Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC 2007a; see Appendix for details). We then used climate simulations to predict seasonal temperature and precipitation in Maine for the next century using a suite of models and the grid points covering Maine. The results discussed here can be used to discern the broad *direction* and *range* of likely changes in temperature and precipitation.

Global Climate Models & Uncertainty

The Earth's climate is overwhelmingly complex and incompletely understood. Any attempts to generate numerical predictions of the future are almost certain to be oversimplified and of limited use in planning for specific locations. Still, scientists do their best, and climate modeling is evolving with frequent advances. Large ensembles of climate simulations reduce uncertainty stemming from perceived weaknesses in any individual model, and provide the "best" consensus from the current generation of climate models.

Regional assessments based on global climate models offer limited fidelity and resolution. The spatial resolution of the global climate models used in international and national climate change assessments ranges from 75 to 250 miles, making regional or local views fuzzy. Recent regional models, such as the one used for the Northeast Climate Impacts Assessment (Frumhoff *et al.* 2006), revised the scale to 5-50 miles.

In the latest IPCC assessment, climate modelers grappled with multiple sources of uncertainty—socioeconomic development, future use of fossil fuels, and limits to climate prediction. Climate projections are almost always presented as a range of outcomes rather than one particular value. This also offers a useful tool to explore mitigation and adaptation options over a range of outcomes, each with a likelihood assigned to it. Given these considerations, current projections of 21st century climate are premised on storyline scenarios that base greenhouse gas emissions on the best estimates of population and socioeconomic growth. The IPCC notes that the key drivers of future greenhouse emissions are demographic change, social and economic development, and the rate and direction of technological change.

Other climate change assessments have typically used a convention of comparing the present to a future time with twice the pre-industrial CO_2 concentration. Thus, the IPCC and other reports are consistent in the "questions" asked of the models. It is important to understand that the CO_2 concentrations may very well increase to three or even four times the pre-industrial levels, leading to global changes that are larger than the commonly reported model results. We thus consider the trends and changes discussed in this report to be conservative estimates, which may well be exceeded in the reality of time.

For further detail on global climate change and climate models, see the Appendix.

Overall, the models show a strong trend in Maine toward warmer and generally wetter conditions in all for seasons over the 21st century with the exception of summer precipitation (*Figure 9*). Projected increases in both temperature and precipitation tend to be greatest in the north, and least along the coast. These warming trends imply a significant shift in the regional hydrology, from a snowmelt-dominated regime (in Northern and Southern Interior climate divisions) to one that shows significant runoff during winter. This shift, coupled with projected precipitation increases in the winters, will likely pose challenges for managing water supplies, flood mitigation, and understanding ecosystem response and potential adaptation during this century. However, slight changes in seasonality of precipitation and increases in evaporation and plant transpiration that are likely to accompany warming all complicate predictions of the net change in water balance.

Maine's Future Climate

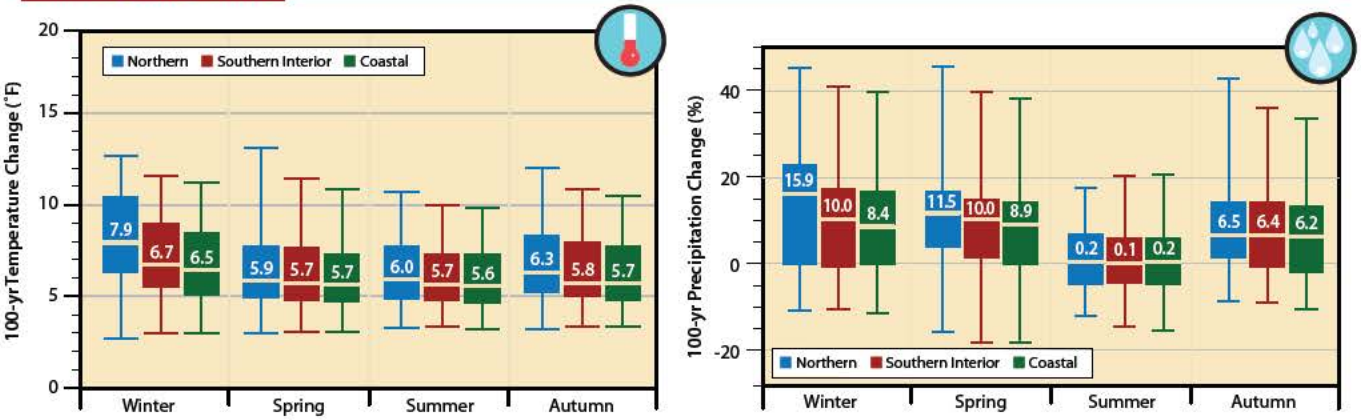
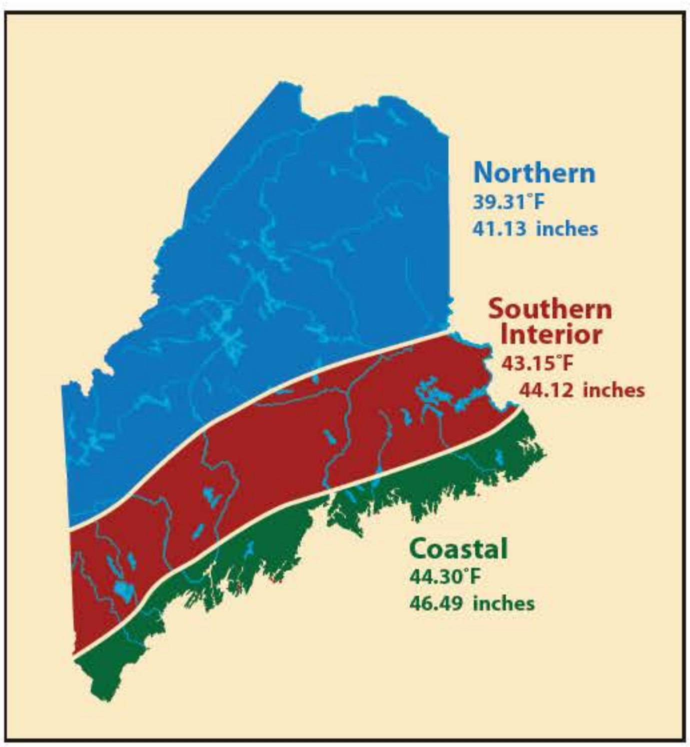
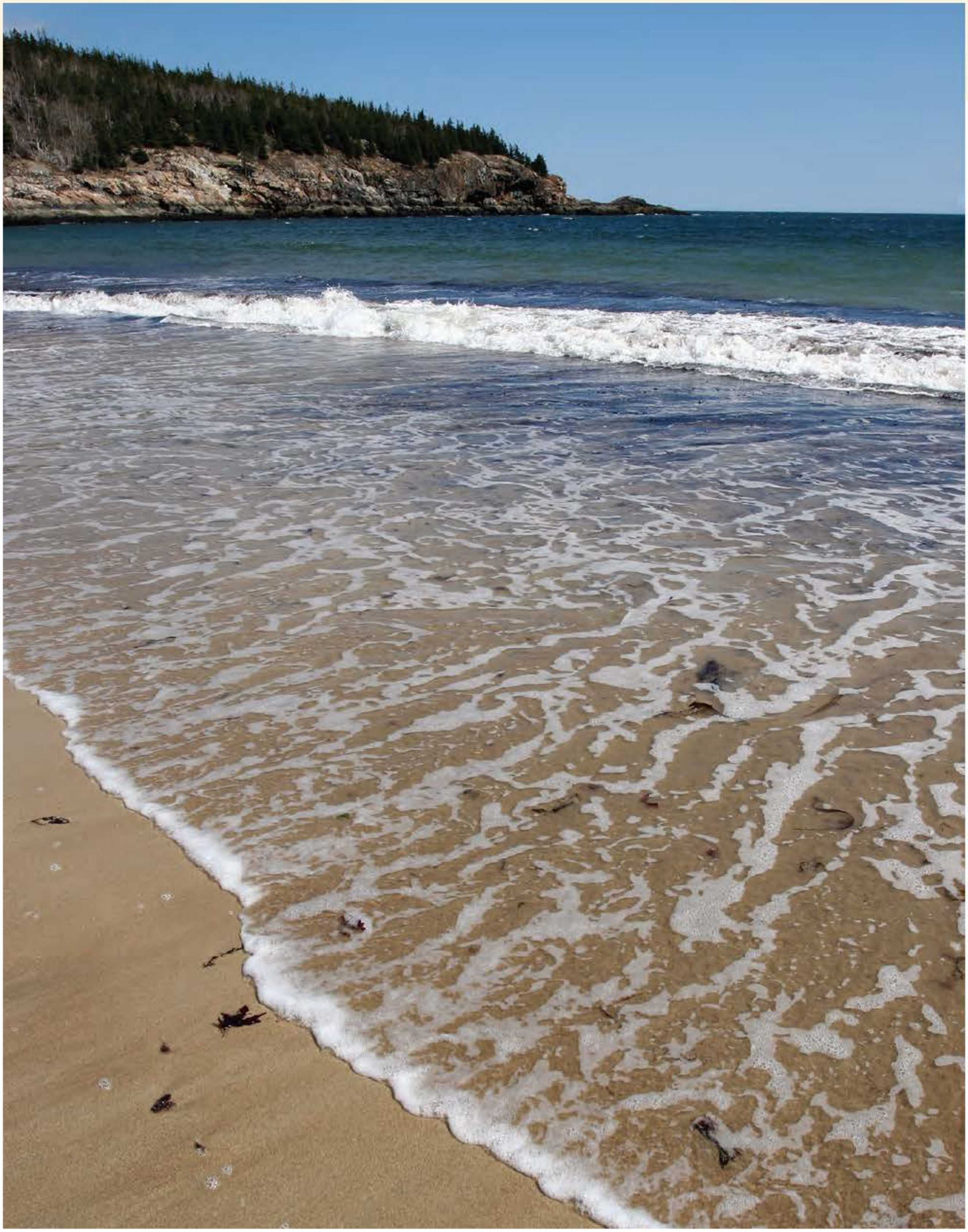


Figure 9 Multi-model prediction of 21st century winter, spring, summer, and autumn temperature and precipitation changes in each Maine climate division from model runs forced with scenario A1B (IPCC 2007a; see Appendix for details). Boxes depict median (solid horizontal line with numerical value), 25th and 75th percentiles for 42 model simulations. Vertical lines span minimum to maximum variation among the models. Special thanks to Cameron Wake for his constructive comments on model output.





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III The Meaning of a Changed Environment: Initial Assessment of Climate Change In Maine

Gulf of Maine

Team leaders Fei Chai and Paul Anderson
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Climate change affects the physical and chemical properties of Gulf of Maine waters, altering the food web that supports commercially important fish, shellfish, and other marine species.

As levels of atmospheric CO_2 increase, more CO_2 dissolves in ocean water, making it more acidic. Shelled animals are particularly sensitive to this acidity.

The current rate of sea-level rise is accelerating from half a foot in the last century to a predicted two-foot rise or more by 2100, threatening to disrupt many of our coastal environments.

Rising sea level will make all storms more damaging, and some assessments predict that severe storms will occur more frequently.

The Gulf of Maine

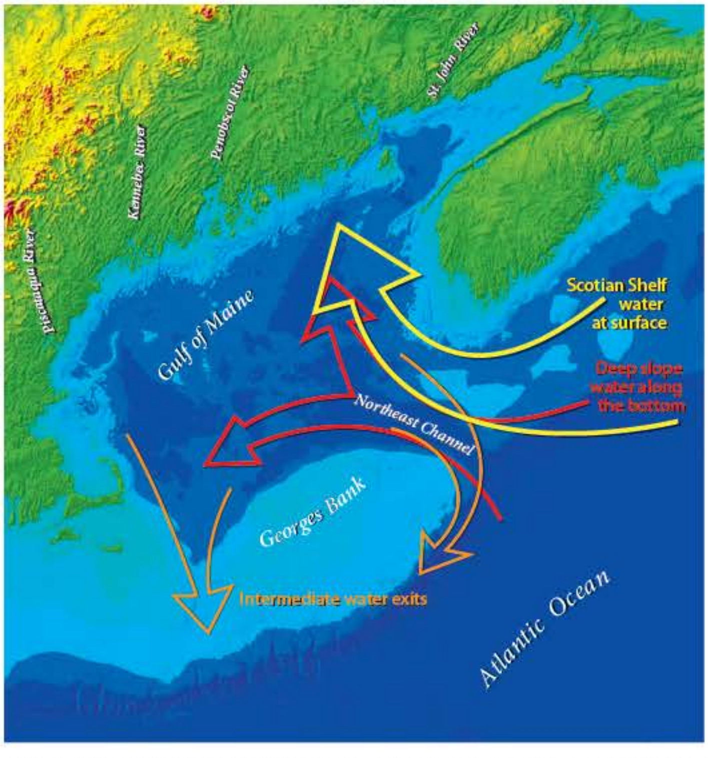


Figure 10 The Gulf of Maine covers a broad area between Cape Cod, MA, and southwestern Nova Scotia. Shallow banks isolate the Gulf from the open Northwest Atlantic Ocean, forming a semi-enclosed sea. The unique oceanographic setting and physical characteristics of the Gulf act together with climate to control nutrient exchange and biological production (Townsend *et al.* 2006).

The Gulf of Maine (*Figure 10*) is one of most productive ecosystems in the world, supporting commercial and recreational fisheries with a combined annual value to the US economy in excess of $1 billion (Steinback *et al.* 2004) and providing upwards of 26,000 jobs (NMFS 2000). The coastal zone of Maine is home to the majority of the state's population and, as the destination for millions of visitors, contributes significantly to the tourism economy.

Over the next century, the Gulf of Maine will experience warmer temperatures and changes in water chemistry such as increased nutrient inputs and ocean acidification. Sea surface temperatures have already increased, as demonstrated by the 100-year record from Boothbay Harbor (*Figure 11*; Fogarty *et al.* 2007). Regional sea surface temperatures have increased almost 1.1°C (2°F) since 1970, and could rise another 3-4°C (6-8°F). Warmer temperatures cause sea levels to rise as warmer ocean water expands, and the rate of sea-level rise has intensified in recent decades, threatening to de-stabilize many of our coastal environments and developed properties.

1 Maine Sea Grant. 2 School of Marine Sciences, University of Maine. 3 Earth Sciences, University of Maine. 4 University of Southern Maine. 5 Maine Geological Survey. 6 Maine Department of Marine Resources. 7 University of Maine Cooperative Extension and Maine Sea Grant

Climate and the Gulf of Maine

Home to a great diversity of marine species, the Gulf of Maine provides safe, sustainably harvested protein for over half a million coastal residents in Maine and millions more people around the world. Climate drives processes in the ocean that in turn control the Gulf of Maine's biological production, affecting commercially valuable species such as lobster (Butler *et al.* 2006), herring (Overholtz and Friedland 2002), shrimp (Clark *et al.* 1999), and various fish species (Mountain and Murawski 1992).

The majority of marine water flowing into the Gulf of Maine comes from the continental slope and enters via the deep Northeast Channel (*Figure 10*; Townsend 1998). Temperature, salinity, and nutrients in the Gulf depend on whether this deep slope water comes from the north, where cold and relatively fresher water from the Labrador Sea flows southwest, or from the south, where saltier, warmer water flows north (and is influenced by the Gulf Stream). The southern slope water has higher concentrations of some nutrients compared with Labrador slope water (Drinkwater *et al.* 2002, Townsend *et al.* 2006).

Large-scale climate patterns (such as the North Atlantic Oscillation; Greene and Pershing 2003) are known to influence the source, temperature, and nutrient content of water entering the Gulf of Maine, in turn affecting the marine food web. For example, during the 1990s, an influx of relatively cold, fresh water that originated in the Canadian Arctic (Smith *et al.* 2001, Greene and Pershing 2007) strongly influenced the plankton community in the Gulf of Maine (*Figure 12*; Pershing *et al.* 2005, Greene and Pershing 2007, Greene *et al.* 2008). The abundance of phytoplankton during the fall and winter fueled an increase in many zooplankton species, which attracted herring.

The North Atlantic is expected to be fresher in the future due to increased precipitation and melting in the Arctic (Curry *et al.* 2003, Greene and Pershing 2007). Based on these predictions and observations in the 1990s, we can expect the Gulf of Maine to be more stratified thermally, and the abundance of zooplankton to increase in the future (although the abundance of a given species may increase or decrease). As colder, fresher Arctic waters flow south along the continental shelf, northern species could actually move south, if temporarily (*e.g.*, Greene *et al.* 2008). These changes will affect the entire marine food web.

Sea Surface Temperature in the Gulf of Maine

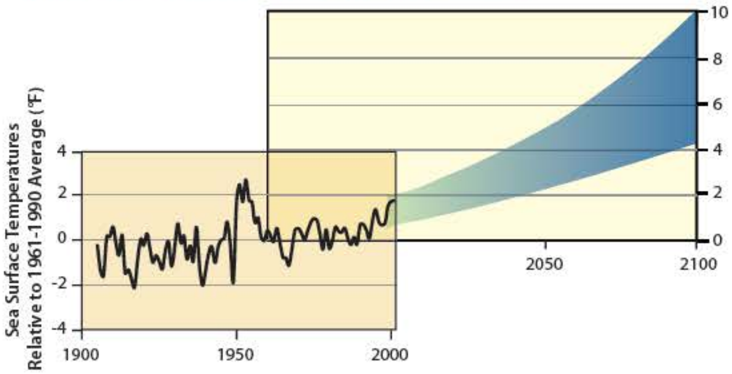
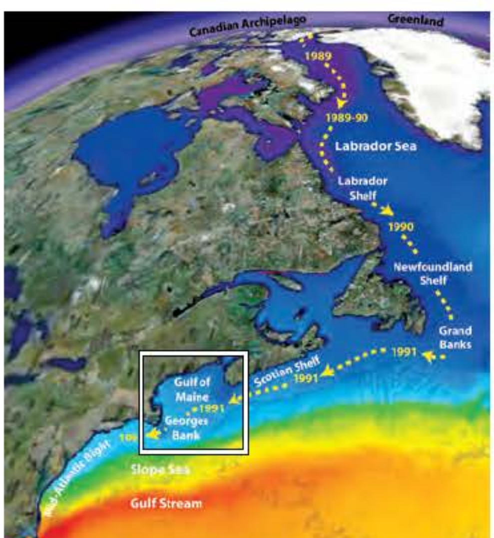


Figure 11 Observed and predicted sea surface temperature anomaly (relative to 30-year average) at Boothbay Harbor (observational data from M. Lazzari, Maine Department of Marine Resources; predicted range based on Frumhoff *et al.* 2006).

Climate-driven Ecosystem Shift in the Gulf of Maine



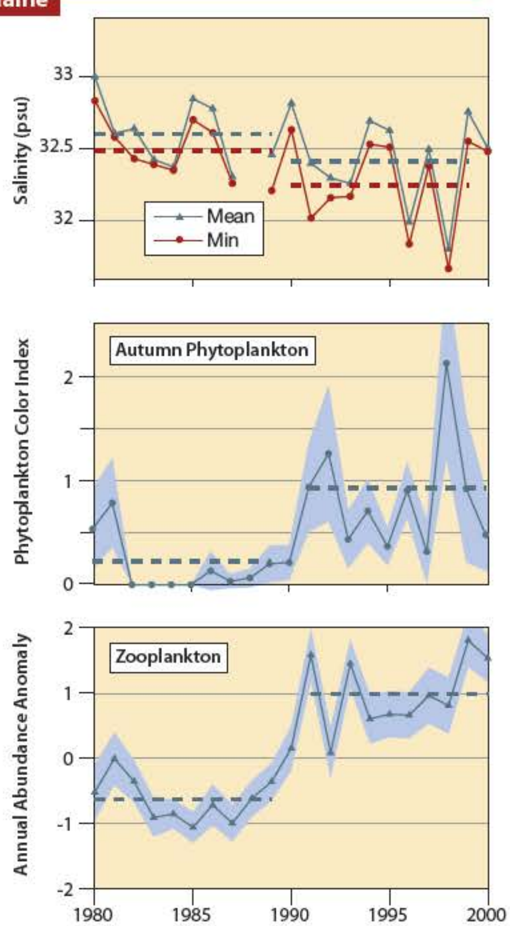


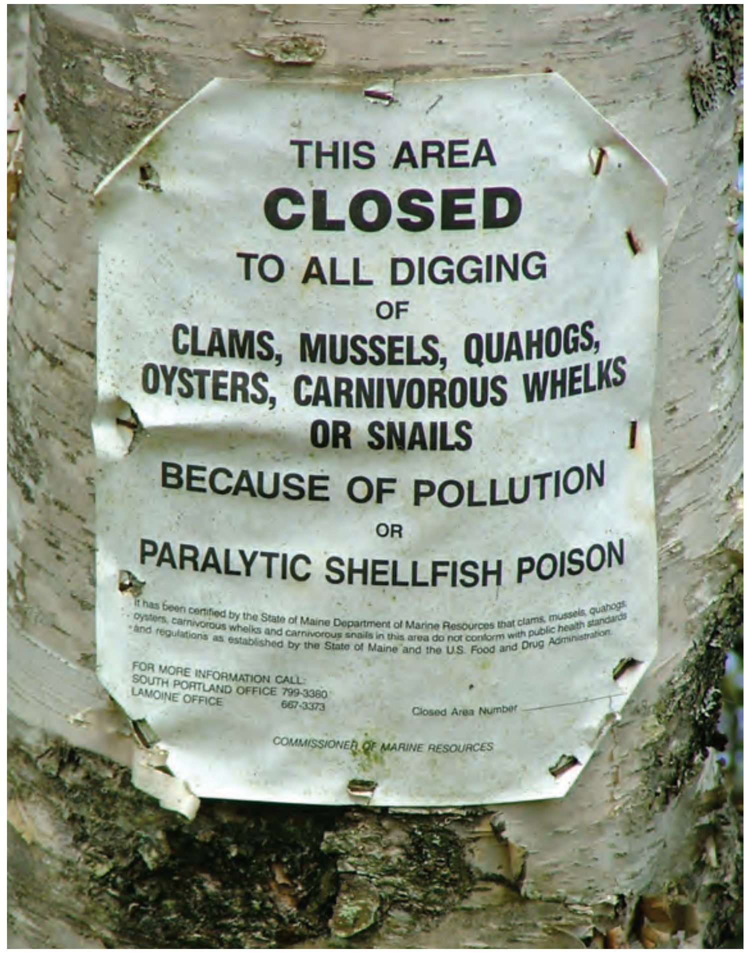
Figure 12 Salinity, phytoplankton, and zooplankton data from the Gulf of Maine and Georges Bank (Greene *et al.* 2008) illustrate ecosystem changes associated with an influx of cold, less salty water originating from melting in the Arctic in the early 1990s (Greene and Pershing 2007). In the graphs, dashed lines are mean values during 1980 to 1989 and 1990 to 1999; shaded areas are 95% confidence intervals. Decadal mean salinities, based on annual mean (blue) and annual minimum (red) salinities, decrease after the regime shift (top). Phytoplankton abundances, based on annual mean phytoplankton color index values, increase after the regime shift (middle). Zooplankton abundances, based on annual mean small copepod abundance anomaly values, increase after the regime shift (bottom).

Climate and ocean chemistry: Trouble ahead for shellfish and corals

The oceans absorb about one third of the carbon dioxide emitted worldwide (Sabine *et al.* 2004). While this pathway is an important "sink" for greenhouse gases, the story does not end there. CO_2 combines with water at the ocean surface to form carbonic acid, releasing acidic hydrogen ions in the process. Today, with 30% more CO_2 in the atmosphere, more of it is entering the world's oceans at a faster rate, making the ocean more acidic (Hoegh-Guldberg *et al.* 2007).

The important result of these chemical reactions is that more acid in the ocean lowers the concentration of carbonate, which is needed by clams, mussels, lobsters, barnacles, sea urchins, coralline algae, and some plankton to build their shells and other hard parts. While not all species are negatively affected by changes in pH, acidic water can dissolve the shells of animals ranging from single-celled algae to reef-building corals; others cannot build shells properly (Orr *et al.* 2005). A damaged shell can affect an animal's physical functioning and reproduction, causing it to stop eating, grow more slowly, and eventually die (Fabry *et al.* 2008). CO_2 levels beyond 1,000 parts per million (the IPCC worst case scenario) will significantly lower the fertilization rates of copepods and sea urchins (Kurihara *et al.* 2004).

Acidification could combine with or magnify other stressors in unpredictable ways. For example, if lobsters build softer shells or change their time of shedding during spring and fall, their susceptibility to shell disease would increase. This could happen without any prior warning signs, as may have been the case in southern New England where sudden mortality events occurred at a time when lobster abundance and landings had been steadily increasing (Castro and Angell 2000). If ocean acidification leads to disturbances in the populations of shelled organisms, other organisms may out-compete them for food and nutrients, leading to ecosystem-wide changes.



R. Lilieholm

The future of Maine's marine resources

The Gulf of Maine lies along a boundary between the subarctic zone to the north and the temperate zone to the south, and represents the southern limit for many cold-water marine species and the northern limit for many warm-water species. Many subarctic species such as the copepod *Calanus finmarchicus*, an important food species for North Atlantic right whales, are at the southern extent of their range in the Gulf of Maine (Adey and Steneck 2001), and these will likely be replaced by temperate species from south of Cape Cod as the Gulf of Maine warms. The Gulf of Maine also is home to many species that can tolerate large temperature variations, though this may not prevent them from being out-competed by more southern species as the seasons and years change.

Some of the species moving in from the south could be commercially valuable. Already during warm years, reports of blue crabs and sea bass increase along the coast of Maine. These changes can happen relatively quickly. European oysters in Harpswell failed to reproduce for 40 years, and then within six years, summer bottom temperatures warmed enough to allow for reproduction (Incze, pers. comm.).

Other new arrivals are potential nuisance or invasive species, such as the Asian shore crab. Within four years of reaching southern New England, the introduced Asian shore crab was established in southern Maine. The population has failed to spread significantly beyond Penobscot Bay (Stephenson *et al.* 2008) likely because warm temperatures are not present long enough for Asian shore crab eggs and larvae to grow. Should sea temperatures continue to warm, the Asian shore crab may spread throughout Maine's coastal zone, potentially resulting in a loss of locally adapted species (see box, "Cod and Lobster" next page) creating an unstable system with less potential for recovery in the face of rapid change (Worm *et al.* 2006).

Another threat to commercial fisheries—and human health—are harmful algal blooms, or "red tides," which occur when any of several species of marine phytoplankton proliferate. The most common species in the Gulf of Maine is *Alexandrium,* which can contain toxins that cause paralytic shellfish poisoning in humans who eat contaminated shellfish. Blooms of these marine phytoplankton are difficult to predict, but are likely a result of a confluence of factors including ocean temperature, nutrient levels, salinity, and oceanographic conditions. The incidence of *Alexandrium* in the Gulf of Maine has been on the rise in recent years and it is not known how climate change will influence the blooms of this organism. Under certain environmental conditions, other potentially harmful phytoplankton species could appear in the Gulf of Maine, including the organisms responsible for diarrhetic shellfish poisoning and amnesiac shellfish poisoning.

Cod and Lobster Fisheries in a Future Climate

Species departures and arrivals will be occurring in the same waters that are home to commercially important species such as cod and lobster. These two species are well-studied and offer examples of the challenges ahead for Maine's fishing industry.

Atlantic cod, the species that once dominated coastal zones throughout the western North Atlantic (Steneck *et al.* 2004), is predicted to decline in the Gulf of Maine by 2100 (Drinkwater 2005). Warm temperatures near the ocean floor will restrict cod habitat, especially for sensitive early life stages, in areas such as Georges Bank (Fogarty *et al.* 2008).

Yet changes in cod distribution patterns will be difficult to detect because the species is so heavily overfished that it is already rare in areas where it was once highly abundant (Myers *et al.* 1997). Once extirpated, local cod populations recover slowly (or possibly not at all; Hutchings 2000) so climate induced changes may be hard to discern over fishing effects, a complication that exists with other species as well.

In contrast, the American lobster fishery is thriving. More than half of the annual US lobster catch is landed in Maine, and landings here have increased steadily since the early 1970s. The remarkable increase in lobster landings over the past two decades could be the result of bottom water warming over that period, which would enhance conditions for settling juvenile lobsters (*Figure 13*; Steneck 2006). Growth rates of lobsters increase with warmer temperatures, as they reach reproductive maturity at a smaller size and at an earlier age.

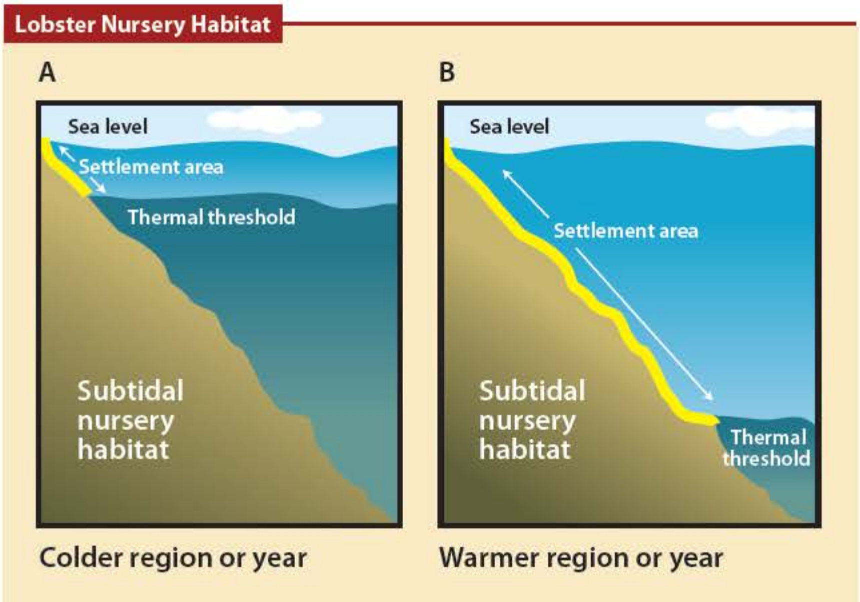


Figure 13 Juvenile lobsters settle where the water in the subtidal zone is warm enough; as surface waters warm, the subtidal habitat available to young lobsters will increase (from Steneck 2006).

Yet fish predation on lobsters is higher in southern New England than in Maine, likely owing to a more diverse assemblage of predators (Steneck, pers. comm). As the Gulf warms, the southern fish community could expand northward, resulting in higher predation. And, finally, at very warm temperatures (above 25˚C/77°F), lobsters become physiologically stressed (McLeese 1956).

Fishermen are already noticing significant changes in the lobster fishery, including altered growth and migration behavior (Hayden and Garratt-Reed 2008). Changes in the lobster fishery have serious implications for Maine's coastal communities, where thousands of licensed lobstermen and women support numerous related industries such as boatbuilding, lobster trap production, bait distribution and transport, and marketing infrastructure. In the event of a collapse, the social landscape along the coast would shift away from commercial fishing with little chance for reversion back to a working waterfront should stocks recover in the future (Steneck *et al.* in prep.).

Climate and the Coast of Maine

The 4,000-plus miles of the Maine coast encompass a wide array of ecosystem types, from salt marshes and sandy beaches to steep cliffs and mountains to numerous bays, inlets, harbors, and estuaries. The coastal zone is also home to the majority of Maine's population, and attracts the majority of tourists.

The coast has always been a dynamic environment, whatever the climate. For the past 2,500 years, sea level has been rising at a slow and relatively stable rate of 0.5-0.9 millimeters (0.02-0.04 inches) per year. During this time, sand accumulated along Maine's beaches, in some places forming dunes that were colonized by maritime forests. Salt marshes established on tidal flats and grew in tune with the tide. Many marshes developed in front of the bluffs of Ice Age deposits that are common along the coast, and guarded these sensitive features from erosion.

Global sea levels have been rising at an accelerated rate of 3.1 millimeters per year (mm/yr or 0.12 inches) since 1993 (IPCC 2007b), a rate that agrees with the higher IPCC projections and suggests that previous assessments may have underestimated future sea-level rise (Rahmstorf *et al.* 2007). This rate is enough to de-stabilize many of our coastal environments. Tide gauge records in Portland show a local relative sea-level rise rate of 1.9 mm/yr (0.07 inches) since 1912 (*Figure 14*).

Half of Maine's coastline is made of bedrock, which resists erosion and generally is not affected by rising seas. The remaining 50% of the coastline is composed of bluffs, sand beaches, and vegetated wetlands (Dickson 2001, Kelley 2004), which are very sensitive to rising sea level.

Bluffs are unstable along 17% of the coastline (Kelley and Dickson 2000), and many bluffs were developed with property before modern setback ordinances existed. An additional 17% of the bluff coast is already armored with seawalls. These structures are expensive and can fail, leading to catastrophic property loss.

Accelerated sea-level rise also threatens coastal wetlands, which provide flood protection and habitat for birds and fish. Salt marshes exist in the narrow zone between the tides; if the sea rises quickly, the marsh must respond by rapidly adding sediment to its surface. Failure to keep up with rising sea level results in waterlogging and death to plants. Many high salt marsh environments may revert to low salt marsh habitats (Slovinsky and Dickson 2006), or may disappear altogether where development blocks their landward migration.

The vast freshwater bogs and marshes that lie just inland of many salt marshes in Maine will die as salt reaches them, completely changing the shape of many stretches of shoreline. Tidal mudflats may be flooded too frequently to serve the millions of hungry shorebirds that visit on their annual migrations. Other low-lying lands are heavily developed and vulnerable to annual flooding due to higher sea levels. Finally, beaches will respond to rising sea level by moving landward or otherwise changing their shape and location.

Almost all of Maine's developed beaches are at risk of damage from a truly large storm that comes at the time of an astronomically high tide (Kelley *et al.* 1989), as was the case during the 2007 Patriots' Day Storm. Over the next several decades, the "100-year coastal storm" could occur every two to three years in the Northeast (Frumhoff *et al.* 2006). Heavier rainfall could trigger sewer overflows, threatening coastal water quality and closing beaches.

Maine Sea Level, 1912-2100

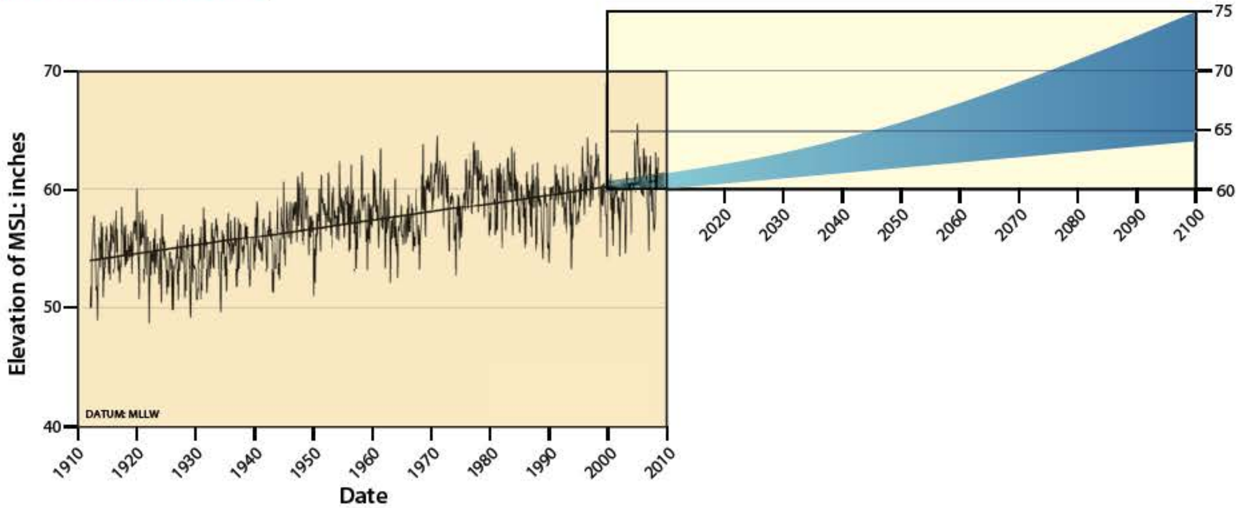


Figure 14 Tide-gauge records in Portland, Maine, show a sea-level rise of 0.07 inches per year (1.77 mm/yr) since 1912 (Belknap 2008). The Intergovernmental Panel on Climate Change (IPCC 2007a) projection of another one-foot rise in sea level by century's end is considered conservative (minimal) by many glacial geologists and climate change experts (Oppenheimer *et al.* 2007; Rahmstorf 2007), because the IPCC projections did not account for increased melting of polar glaciers, and they are already behind observations of sea-level change from satellite data. Future sea-level rise may be triple those of the IPCC projections (Rahmstorf 2007).

Increased ocean temperatures may increase the frequency and intensity of hurricanes (Emanuel 2005, Webster *et al.* 2005). Nineteen hurricanes have made landfall in the Northeast since 1850. Six occurred in the relatively active period between 1935 and 1960. If the region were to experience a similar period of activity today, it would result in about $55 billion in damage, not including damages to natural ecosystems or the costs of lost recreation and tourism opportunities (Ashton *et al.* 2007).

In southern Maine, a one-foot rise in sea level will make all storms more damaging (FEMA 2003) with serious economic and ecosystem consequences to the region and state. In York County alone, over 260 businesses representing $41.6 million in wages are at risk from coastal flooding and the resulting property destruction and higher insurance costs, although it is possible that long before storm surge reaches the hotels and restaurants along Route 1, the beaches which draw tourists to southern Maine will have disappeared (Colgan and Merrill 2008).

Opportunities & Adaptation

Changes in the ecology of the Gulf of Maine will likely result in population shifts for many marine species. This may result in the opportunity for commercial fishermen to target new or different species. Recreational fishing opportunities will also change with a strong likelihood of more sport fish being available. Commercial fishermen also need to be prepared to use different fishing gear, and to expect modified fisheries management regulations.

Specific fisheries and related industries with significance to the state warrant special focus. For example, with the potential increased vulnerability of lobster to disease due to warming and ocean acidification, increased vigilance should be practiced in monitoring the health of lobster populations.

Supporting and expanding oceanographic observation networks, such as the Gulf of Maine Ocean Observing System (GoMOOS), will ensure that timely and accurate environmental data are available to managers. For example, up-to-date information on potential storm surge threats will enable emergency management officials to establish evacuation routes and other emergency responses. Observation networks can complement existing monitoring programs, such as those for paralytic shellfish poisoning. The state's red tide monitoring program must be maintained and expanded to include other, less typically harmful algal bloom species (and toxins) of concern. Maintaining monitoring of marine organisms is also important for tracking contaminant levels (*e.g.*, persistent organic pollutants) and the incidence of disease.

Coastal managers are already dealing with many of the problems expected to worsen with climate change. Maine's coastal communities need tools to identify locations and properties that are vulnerable to inundation due to sea-level rise and storm-related surges. Risk assessment tools to assess the potential need to remove or relocate infrastructure such as wastewater treatment plants, docks, and piers are required. With the increased risk for property loss on the coast, an assessment of current flood insurance programs and their applicability to Maine's coastal residents should be conducted in order to help property owners understand their vulnerabilities. Maine has been very progressive in beach management strategies and related regulatory structures (*e.g.*, Sand Dune Rules), but the need to review and amend these policies is ongoing to ensure that adaptive management principles are being implemented.

Knowledge gaps

The IPCC model projections are too coarse to predict how the Gulf of Maine will change. Regional ocean modeling approaches with higher resolution and incorporating coastal processes are needed. What are the future temperature ranges, physical conditions, and nutrient inputs in the North Atlantic?

What do we need to know about marine plankton population dynamics in order to predict ecological changes resulting from food web-based changes in other species?

Ocean acidification has the potential to be very damaging to many species in the Gulf of Maine. What are the trends in local pH, and the relative risks to wild fisheries, capture fisheries, and the general ecology of shelled organisms?

Science-based management of the coastal zone requires practical knowledge of where and when not to build roads and structures, the effects of coastal armoring and beach management, and realistic plans for ecosystem management and restoration within planning-level time frames of 5, 10, and 15 years (see Ashton *et al.* 2007, Tribbia and Moser 2008). How will Maine's shoreline respond to rising sea level and storms? Do we have the information and capacity to manage the coast in a sustainable way? How will changes in freshwater flows and runoff affect pollutant loads, temperature, and salinity of coastal waters?

Freshwater Ecosystems

Team leader David Hart
Authors David Hart,[1] Shaleen Jain,[2] John Peckenham,[1] and Josh Royte[3]
Reviewer Barbara Vickery[3]

Climate change will affect Maine's lakes, rivers, and wetlands by altering the timing and magnitude of precipitation, length of growing season, spring ice-out, and spring runoff.

As a result, warming water will reduce the distribution of cold-water fisheries, the ice fishing season will be shorter, and local flooding and stream erosion damage may become more common in some areas.

Freshwater supply, especially in coastal communities, will become less reliable due to altered hydrology, rising sea level, and increased demand.

D.J. Fernandez

Thanks to a history of glaciation and a humid climate, Maine has thousands of lakes and ponds, thousands of miles of streams and rivers, plentiful groundwater aquifers, and numerous wetlands such as bogs, swamps, and marshes. All this water supports a diversity of ecosystems, plants, and animals, and provides valuable services to humans, such as drinking water and crop irrigation.

Climate and freshwater ecosystems

Temperature, precipitation, and timing of significant aquatic events (intense rain, ice-out, spring flooding, drought, etc.) are "master variables" that influence freshwater ecosystems and that are predicted to change according to all climate model predictions (*e.g.,* this report and Hayhoe *et al.* 2007). Local effects, such as stream flow, have been linked directly to global-scale climate behavior (Kingston *et al.* 2007).

Changes in temperature will affect the abundance and distribution of freshwater plants and animals. Increased air and water temperatures will increase overall production in lakes, ponds, rivers, and streams, as plant growth is enhanced in warmer surface waters. Warmer temperatures and more frequent rainstorms also might increase the incidence of West Nile virus and other mosquito-borne diseases (Poff *et al.* 2002).

This preliminary assessment predicts a wetter future, with more winter precipitation in the form of rain (*Figure 9*). Other assessments forecast increased intensity of precipitation (Hayhoe *et al.* 2007). Although it is not possible to predict specific changes at a given location, several 100- to 500-year precipitation events have occurred in recent years.

Changes in climate will affect the inputs of water to aquatic systems in Maine and changes in temperature will affect freezing dates and evaporation (Huntington *et al.* 2003). These changes will drive changes such as earlier spring runoff, decreased snow depth, greater lake level fluctuations, and saline intrusion of coastal aquifers. A number of stream gauges in Maine show a shift in peak flows earlier in spring and lower flows later in the season (*Figure 15a;* also Hodgkins and Dudley 2006). Similarly,

1 Senator George J. Mitchell Center for Environmental & Watershed Research, University of Maine; 2 Civil and Environmental Engineering, University of Maine; 3 The Nature Conservancy

Changes in Timing of Maine River Flows, 1952-2007

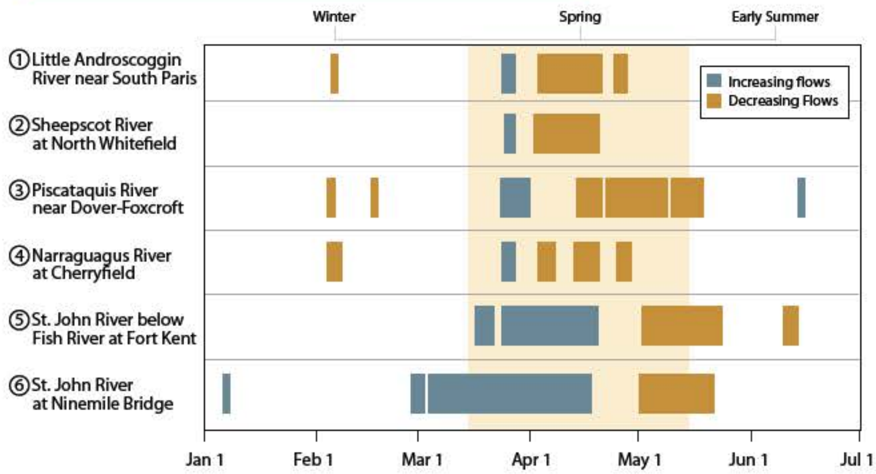
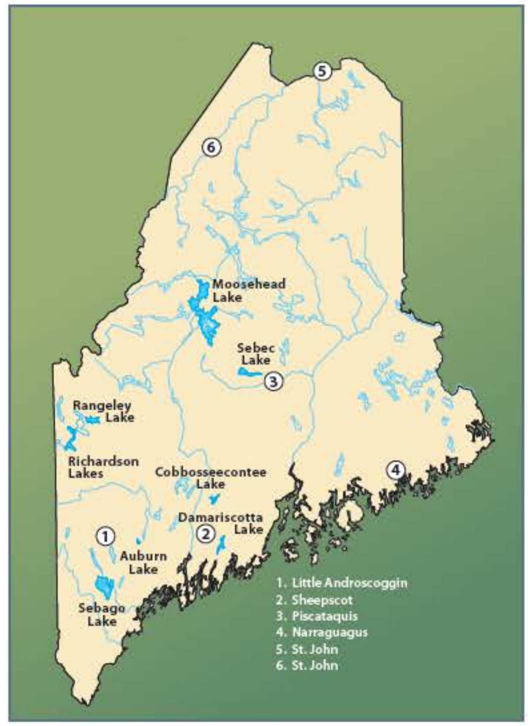


Figure 15a Stream gauges across the state (see maps) show statistically significant increases (blue) and decreases (brown) in river flows in late winter and spring, respectively. The shaded block represents the regulatory season used by the Maine Department of Environmental Protection to prescribe season-specific Aquatic Base Flow levels. A Mann-Kendall statistical test on daily streamflow data confirmed trends during the period (Ricupero and Jain 2008).



Ice-out Records for Selected Maine Lakes

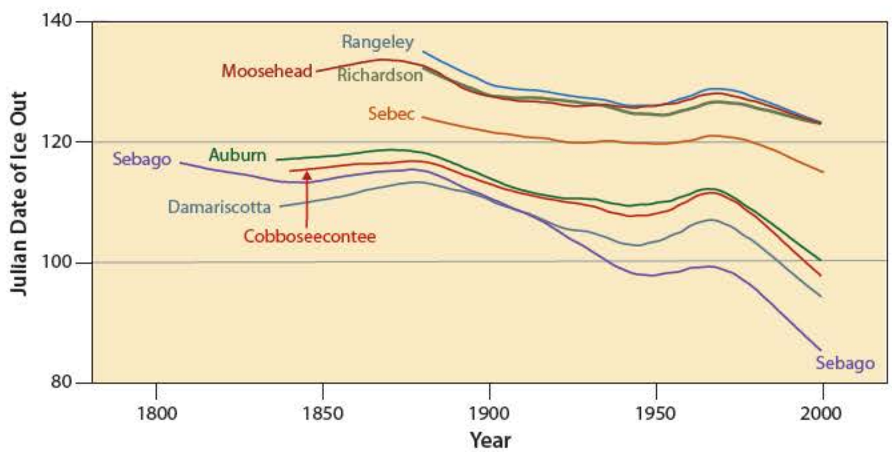


Figure 15b Lake ice-out dates, or the dates of ice break-up, are the annual dates in spring when winter ice cover leaves a lake. Lake ice-out dates in Maine have advanced by up to two weeks since the 1800s (Hodgkins *et al.* 2002).

lake ice-out dates in the New England region have advanced by up to two weeks since the 1800s (*Figure 15b*; Hodgkins *et al.* 2002, Hodgkins *et al.* 2003), resulting in shorter seasons for ice-fishing, skating, skiing, and snowmobiling. Southern Maine could ultimately stop having safe ice conditions.

The timing of spring snowmelt influencing river flows and the warming of waters are critical events in the lives of water-dependent wildlife. Warming water and spring rains trigger spawning for salamanders and frogs, while spring flows and water temperatures signal hatching times for aquatic insects like mayflies, stoneflies, and dragonflies. Water levels and temperatures also cue migration of sea-run fish such as alewives, shad, and Atlantic salmon into our rivers, and the arrival or concentration of birds that feed on these fish.

Lower flows in summer will reduce aquatic habitats like vernal pools, cold-water holding pools, and spawning beds. If we experience longer periods without rain, Maine's thousands of acres of peatlands, marshes, and forested swamps could dry out, releasing stored carbon and other greenhouse gases. Increases in severe storms (and droughts in between) will change the boundaries of wetlands as they adjust to fluctuating water levels. For example, the unique floodplain forests of the Saco, Penobscot, upper Kennebec, and Sebasticook rivers could convert to meadow or upland forests.

Changes in the water cycle will interact with changes on land. Water flowing through watersheds where tree and plant communities are changing in response to climate will deliver altered inputs of nutrients and organic matter into lakes and streams, changing their chemistry and biota. For example, the trend of decreased calcium in lakes is leading to the demise of zooplankton species that are important to lake food webs (Jeziorski *et al.* 2008).

Surface water recharges groundwater, and groundwater provides baseflow to streams and rivers during periods of low rainfall. As the surface water regime changes, so too will the timing and delivery of recharge to groundwater.

More frequent large storms and scouring flows will damage habitat, especially where aquatic systems are already stressed by increased runoff, poor water quality, and siltation of lakes and stream beds. These disruptions ripple through watersheds, altering stream flows and re-distributing sediments, affecting infrastructure such as the size and ratings of culverts and bridges. As a result, roadway flooding, dam breaches, or wash-outs may occur more frequently.

The future of Maine's freshwater resources

Some of the ecosystem processes affected by changes in temperature and hydrology have direct societal costs. Maine lakes attract residents and visitors for fishing, paddling, and wildlife watching, generating $3.5 billion each year (Maine Congress of Lake Associations 2006). Many of Maine's lakes supply high-quality drinking water. Warmer water and increased nutrients from stormwater runoff threaten to degrade lake water quality through more frequent or more intense algal blooms, with resulting effects on waterfront property values. Severe storms can flood waterfront properties, causing expensive damage.

Demands on freshwater supplies in the US are increasing, and water shortages are likely in the near future (GAO 2003). In the New England region, freshwater withdrawals are projected to increase by 550 million gallons per day, or 15%, over the next 20 years (Brown 1999). In coastal areas, increasing residential development and tourism will raise the demand for water at the same time as warmer temperatures and salt water intrusion threaten water quality.

Opportunities & Adaptation

While freshwater availability is a critically important factor influencing socioeconomic development, the maintenance of water quality and ecosystem services can have far-reaching effects on the long-term sustainability of river systems. In a changing climate, added stresses from urbanization and land-use change present an important challenge in balancing human and ecosystems water needs. Maine has recently promulgated a first-in-the-nation water regulation that limits water withdrawal from rivers and lakes with a goal of maintaining the integrity of the river and riparian ecosystems. These laws regulate human consumptive uses to protect aquatic systems, based on *current* hydrological conditions. Compliance with these regulations may be impossible when hydrologic conditions change in response to climate shifts, unless flexibility and adaptive management are incorporated during rulemaking.

It is not unreasonable to imagine a time in the future when water-starved regions begin eyeing Maine's abundant freshwater supplies, and the potential for conflict inherent in such a scenario. We have already seen suggestions of this conflict, in Downeast Maine where blueberry farmers drew irrigation water from rivers home to endangered Atlantic salmon; in western and southern Maine where commercial bottlers continue to search for and develop new water sources; and in coastal Maine where the 2001-2002 drought magnified imbalances of drinking water supply and demand (Schmitt *et al.* 2008). Although public debate has begun on how water from Maine could/should be sold for profit by private companies, water resource managers and other communities should anticipate that the value of "their" water could become more contentious. As peaks in demand increase, water managers will have to look further afield for new supplies, or pursue costly interconnections with neighboring supplies, at the same time that suitable water sources become scarcer.

Finally, we need to know the extent to which key species (*e.g.*, brook trout) can respond to increasing water temperatures by moving to cooler (*e.g.*, more northerly) habitats, and how such movements are constrained by barriers to mobility, such as culverts. Depending on the answers to these research questions, we might accelerate barrier removal efforts to increase the resilience of key species. Policy will need to address what measures will be taken to protect ecologically unique species in the event that they are unable to adapt. For example, constructing and managing artificial wetlands may be needed to preserve these ecosystems from seasonal drought.

Knowledge gaps

Where are freshwater ecosystems (lakes, floodplains, wetlands) most vulnerable to floods and droughts, and are management techniques (*e.g.*, maintaining water levels) available to help maintain resilience in the face of these extremes?

Increased warming is likely to increase the susceptibility of Maine's aquatic flora and fauna to new pests and pathogens. How will this affect large areas of habitat conversion and species loss or displacement?

Roads with improperly sized and placed culverts and bridges fragment river and stream habitat, preventing the movement of aquatic species. Roads and related development also alter the surface and subsurface flow of water through the landscape to aquifers, streams, and ponds. How will less predictable weather and seasonal changes enhance or interact with these stresses?

Much of our infrastructure for water delivery, wastewater transport, and transportation is not designed to handle the predicted increase in intense precipitation events. What happens when flood zones, bridges, culverts, and water treatment plants designed for "20-year" storms are overwhelmed with sediment and other precipitation-related pollutants? How will Maine's current hydroelectric power regime be influenced by expected changes in seasonal hydrology, storm events, and river levels?

Forests

Team leader Richard Jagels
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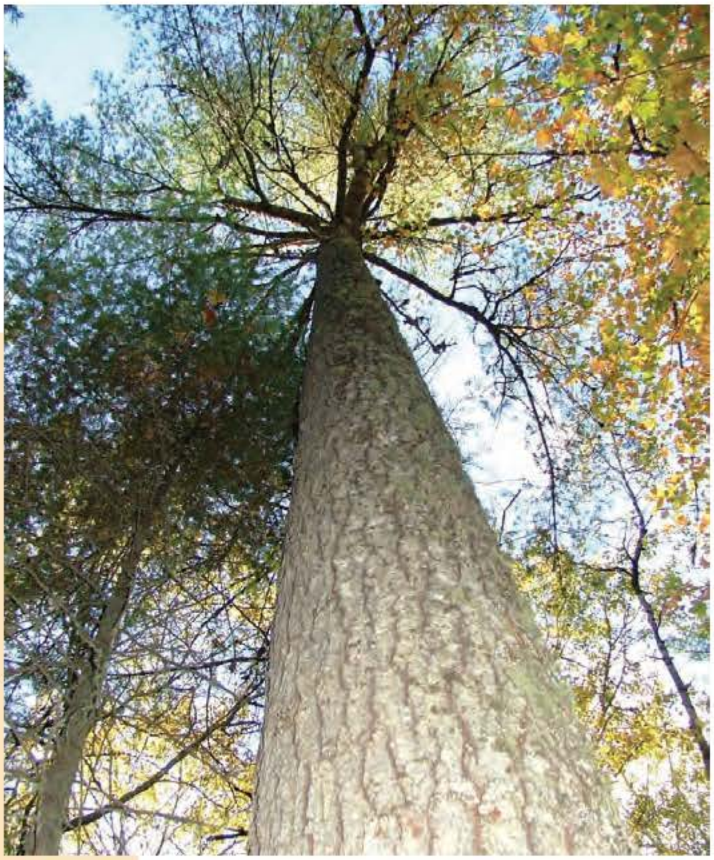
Reviewers: John Campbell,[4] Lindsey Rustad,[4] Barbara Vickery,[5] Robert Wagner,[6] and Alan White[1]

Maine forest composition has shifted in response to a changing climate over millennia. Today's spruce-fir forests are relatively recent, their populations having expanded southward in the past 500-1,000 years.

Maine will continue to have abundant forests, but the composition of the forest and the way trees grow will be different from today. Warmer temperatures and the fertilization effects of CO_2 and nitrogen may promote accelerated tree growth. Increased disease, insect infestations, and forest fires threaten to temper predicted increases in wood production.

Forest management will play a critical role in maximizing forest utilization opportunities while maintaining forest sustainability and carbon storage.



Rob Lilieholm

Maine is the most heavily forested state in the nation, and our forests are diverse in both form and function (McMahon *et al.* 1990, Fernandez *et al.* 2000). These extensive forest resources have long supported a forest-based economy, and although some traditional forest product industry sectors have declined in recent years, we are witnessing a renewed interest in the importance of forests for new products like wood pellets and ethanol, for services such as carbon storage and water quality protection, and for tourism. The forest products industry is discussed later in this report; here, we describe forest-climate interactions and anticipated changes to the forests themselves.

Climate and forests

Forest-climate relationships of the past provide important clues about the rate and direction of change in forest composition that we are experiencing today, and are likely to face in the coming decades and centuries. These relationships are recorded in lake sediments, which contain fossilized pollen and other plant matter that reflect the makeup of the lake's surrounding forests over time.

Research on Maine lake sediments indicates that between 9,000 and 5,000 years ago, temperatures were as much as 2°C (4°F) warmer and the air was considerably drier than today. White pine was widespread and abundant, probably because frequent fires created conditions favorable for seedling establishment (Jacobson and Dieffenbacher-Krall 1995). During that same time, both white pine and hemlock grew at much higher elevations than their present upper limit in the White Mountains of New Hampshire and the Adirondack Mountains of New York (Davis *et al.* 1980).

Conditions changed considerably during the past few thousand years, however, as the climate became cooler and moister, fires became less frequent, and the distribution of white pine steadily diminished. As white pine (and oak) became less abundant, other tree species became more prominent, and the forests began to resemble those of modern times. Within the past 1,000 years, boreal trees, including spruce and balsam fir, expanded along the southern margins of their distribution in Canada and along the northern tier of the US from Minnesota to Maine (*Figure 16*; Schauffler and Jacobson 2002). The strong expansion of spruce in the Great Lakes-New England region, especially in the past 500 years, appears to have been associated with summer cooling during the Little Ice Age (1450-1850 AD).

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Spruce Forest Cover in the Northeast

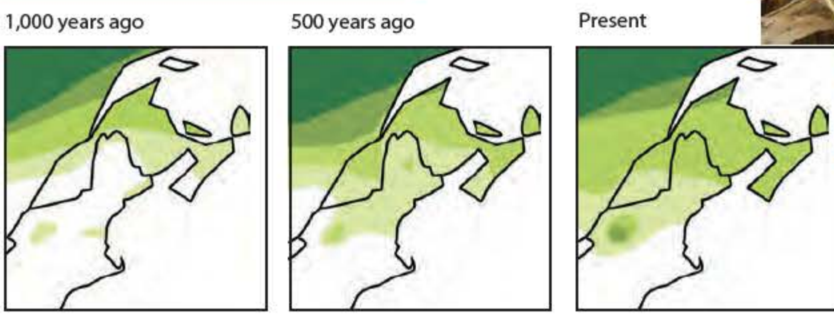

Figure 16 Spruce forest cover in northeastern North America as revealed by percentage of spruce pollen in lake sediments (Schauffler and Jacobson 2002). [Darker green indicates greater density of spruce.] Spruce cover has increased over the last 1,000 years as the regional climate became cooler and wetter.

Climate-driven changes in Maine's forests have not been uniform across the state. Just as there is a strong coastal-inland gradient in climate today, similar patterns influenced the vegetation of the state for much of the past 10,000 years since the ice sheets withdrew from Maine. Paleoecological studies show that spruce forests have persisted along the narrow coastal zone, even when white pine and oak dominated inland areas (Schauffler and Jacobson 2002). Then, as today, the dramatic twice-daily tidal mixing of the Gulf of Maine brought deep, cold water to the surface, and southwesterly currents along the coast brought cool temperatures, often accompanied by fog. This dramatic "coastal cooling" effect will continue into the future, allowing spruce-fir forests to remain on a narrow strip of east-coastal Maine, in greater contrast to inland areas.

Maine's future forests

Several recent efforts to model forest response to changing climate predict that increasing temperature, changing water balance, rising CO_2 concentrations, and ongoing atmospheric deposition of nitrogen are all important and interacting factors that are changing the way northeastern US forests grow (Campbell *et al.* 2008, Ollinger *et al.* 2008). In general, models predict that increased CO_2 and nitrogen in the atmosphere will lead to accelerated growth in some tree species while slowing growth in other species. The increased growth is attributed to more wood production, and less foliage and root production likely as a result of summer drought stress. These models do not include the effects of forest management on the trajectory of change, despite the potential for significant changes in management approaches and objectives in the years ahead.

Current and Projected Forest Cover in the Northeast

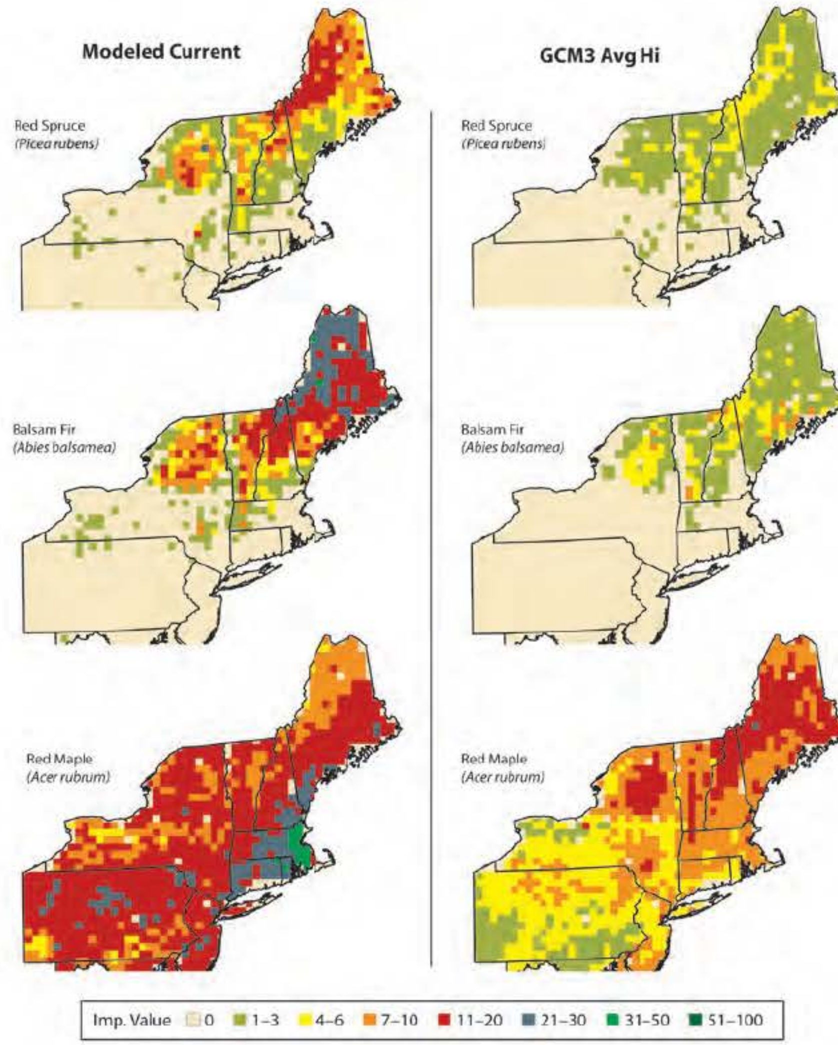

Figure 17 Maps showing modeled current and predicted future ranges for three important Maine tree species based on Forest Inventory and Analysis (FIA) data (Prasad *et al.* 2007) and 38 predictor variables. Future model projections were made using the average of three general circulation models (CM3Avg Hi), and the high future greenhouse gas emission scenario (A1fi) for potential suitable tree habitat in the year 2100 (Iverson *et al.* 2008). Importance values reflect species basal area and number of stems as determined by FIA protocols.

Changes in temperature and precipitation will influence processes related to water stress in trees. In general, periods of drought will result in growth declines. Species that are more sensitive to water stress than to temperature alone, such as red spruce, may decline in interior Maine while persisting in habitats of higher moisture availability such as the Downeast coast, offshore islands, and wetlands. Balsam fir, essentially a boreal species, could become scarce in Maine (*Figure 17*).

Fortunately, many of our tree species can tolerate moderate to wide temperature gradients, an indication of considerable genetic flexibility. Some of Maine's species with larger ranges, such as red maple, may be genetically adapted to wider climate regimes, and would be expected to increase in abundance. Other species with more limited genetic resilience like red spruce may face local extirpation.

Changes in forest composition can be slow for existing forests because of the longevity of canopy tree species and the relative tolerance of mature trees to environmental stresses. Therefore, the rate of change will, to a large extent, depend on disturbances such as fires, storms, insect or disease outbreaks; and management practices such as harvests, artificial regeneration, and forest fragmentation (Logan and Gottschalk 2007). Hurricanes, ice storms, and nor'easters clear the way for the establishment of new individuals, both of current species and new migrants from the south, and represent opportunities for rapid change in the forested landscape.

For example, as the boreal forest shifts further northward, increased drying and summer heat are expected to disproportionately stress the central and southern forests of Canada (Notaro *et al.* 2007). Signs that this process has already begun can be seen in recent increased fire frequency in Canada's boreal forests, and by unusual outbreaks of mountain pine beetle in northern British Columbia, resulting from prolonged drought (Kurz *et al.* 2008). These events can undermine the carbon sequestration potential of forests, and could represent important threshold events that accelerate landscape change. These changes are not confined to boreal forests.

Many of the species that currently dominate Maine's forests are adapted to be competitive on relatively acidic, nutrient-poor soils. These adaptations could be less useful in future conditions of increased CO_2, and greater availability of some nutrients, which would favor fast-growing, competitive deciduous species like red maple (*Figure 17*), and "weedy" shrubs like brambles and invasive species.

The climate scenarios (*Figure 9*) indicate warmer temperatures but slightly higher precipitation throughout the year, coupled with possible increased drought late in the growing season. Thus, the potential for continued forest cover in Maine is high, though suitable habitat for individual tree species is likely to shift.

Opportunities & Adaptation

The growing emphasis on managing carbon emissions is rapidly changing the way we think about the role of forests in greenhouse gas mitigation, and the consequences of forest management decisions with respect to forest carbon storage (sequestration). Forests store more carbon than nearly all other land uses (IPCC 2007a, 2007b). According to a recent estimate, Maine forests represent 1,686 million metric tons of carbon, up to 80% of which is below ground in soils (Birdsey and Lewis 2003, Fernandez 2008). While the most rapid carbon accumulation in trees can occur with fast-growing species above ground, the highest whole-ecosystem carbon accumulations are typically in old-growth forests.

Changes in other forested regions beyond Maine could create opportunities here. Forests in the southeastern US will likely suffer disproportionately from global warming, perhaps even converting to dry scrubland. These forests capture an estimated

13% of greenhouse emissions from the region (Han *et al.* 2007). With increasing drought and consequent increases in insect and disease outbreaks, the potential for carbon sequestration is likely to decline substantially in the southeastern US as more drought-resistant tree species with reduced commercial potential may be needed to maintain some forest cover. Maine and other northern New England states will thus have increased opportunities to expand forest-based industries and also to increase carbon sequestration in the coming decades by focusing on species adapted to the new climate and suited to the emerging markets.

Forest management will play a critical role in maximizing forest utilization opportunities while maintaining forest sustainability and carbon storage. Forest management systems can have a profound influence on the speed of change in forest ecosystems. Silvicultural practices generally focus on regenerating new forests following harvest or other disturbance. It is in the early stages of development (seedling, sapling) that trees are most susceptible to stress. Forest managers can influence the stress experienced by young trees by altering the physical environment (*e.g.*, temperature, humidity, soil water, wind, snowpack) and the potential competitors to be faced by the regenerating forest. Silvicultural practices can enhance retention of critical species, or facilitate introduction of new species that are better adapted to future environments and markets.

Rob Lilieholm

Management strategies and objectives need to address the most relevant forest production and carbon sequestration goals under expected disturbances, while providing an insurance cushion for unpredicted possibilities. For instance, spring warming and summer drought will have disproportionately greater influence on faster-growing species that are not drought tolerant (Welp *et al.* 2007). By avoiding the vulnerabilities of single-species forests, mixed-forest communities might be more resilient and thus provide some security in the face of uncertainty (Bodin and Wiman 2007).

Finally, it should be noted that forest cover can significantly affect local climate even in the absence of broad-scale climate change. This has been documented for the Brazilian Amazon and in East Asia, where deforestation influences the summer monsoon season (Sen *et al.* 2004). Maintaining a substantial forest cover in Maine will help to preserve economic and environmental benefits, including a healthy hydrologic cycle, and provide protection against catastrophic weather events.

Knowledge gaps

What are appropriate prescriptions for forest management in Maine during the period of transition over the next century? What are the thresholds of forest response that can dramatically alter the anticipated rate and direction of change in forests? What ecological and economic thresholds will determine the viability of new opportunities for the forest sector? A recent report of the US Climate Change Science Program (Fagre *et al.* 2009) focused on the importance of thresholds in ecosystem response to climate change calling for (1) measures to increase resilience in ecosystems to slow the crossing of thresholds, (2) the identification of early warning signals of impending threshold changes, and (3) the use of adaptive management strategies to deal with new conditions.

What are the critical research needs for forests? Are there new incentives for research in Maine, such as experimental plantations of tree species that have potential to thrive in a warmer climate and have unique advantages in emerging bioproducts markets?

How will increasing development pressures on Maine's forestland (see box on page 45) reduce the land base available for both carbon storage and forest resource goals?

Can we identify emerging biological responses to a changing climate through monitoring of forest growth, physiology, phenology, and biogeochemistry, knowledge which is essential for planning and making decisions?

Biodiversity

Team leader Malcolm Hunter

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Some plants and animals will disappear from Maine as new ones arrive and become established. The state's official list of endangered and threatened species will likely grow.

The species most likely to increase in the state are southern species that are at the northern edge of their range in Maine, warm-water fish species, and especially invasive species.

Maintaining or restoring landscape-scale connectivity is a priority, because a landscape fragmented by roads, dams, and development presents a barrier to many species during the process of geographic range shift.

From an ecological perspective, Maine is defined in large part by the diversity of plants and animals that live here, and many of these species also have important economic and cultural roles. Consider a future in which climate change leads to sharp declines in populations of lobster, brook trout, moose, loons, puffins, or sugar maple.

Climate and biological diversity

Climate is a key factor determining where plants and animals live, and how abundant they are in any given location. All of Maine's species existed on the Earth hundreds of thousands, and in most cases millions of years ago. Thus, the species in Maine today have experienced dramatic climate change before, and their distribution and abundance have shifted in response many times during the recent ice ages.

Such shifts are easier for some species than others. Larger mammals, river fish, birds accustomed to long-distance travel, and those plants that disperse seeds can spread into new habitats more readily than relatively sedentary animals such as snails and salamanders or plants with heavy seeds. Furthermore, species that are confined to uncommon, isolated habitat patches will find range shifts relatively difficult compared to species associated with widespread habitats. In some cases species could be lost from Maine, or for those species with narrow geographic ranges, even driven to global extinction.

Maine's future flora and fauna

In a warmer climate, Maine could lose some of its most iconic species such as loons, moose, and puffins. Many species reach the northern or southern edge of their geographic range in Maine (*Figure 18*), and climate change will almost certainly lead to significant changes in Maine's overall assembly of plants and animals. This unusual concentration of edge-of-range species occurs because of Maine's unique climatic diversity (as described in "Maine's Climate Past, Present, Future," page 10). While we can anticipate dramatic broad changes in Maine's biota, it is difficult to make confident, precise predictions about the future of any particular species because climate is just one element of a species' habitat and because our understanding of the ecology of most species is quite limited (*e.g.*, birds, see box on page 31; Walther *et al.* 2002).

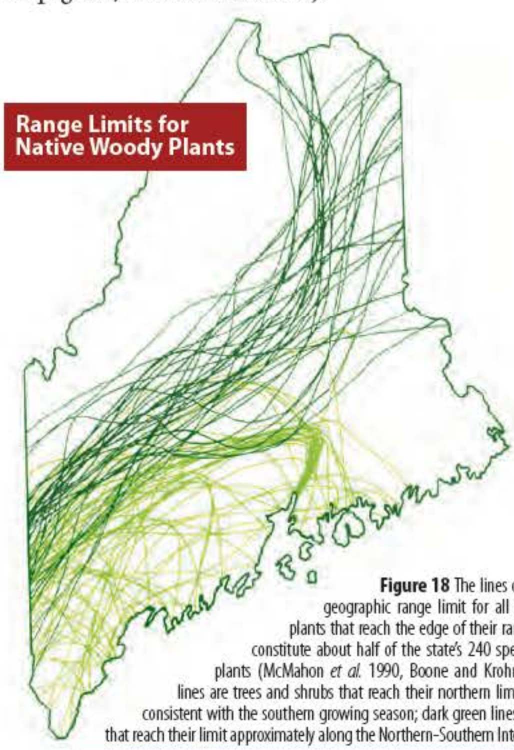

Figure 18 The lines on the map show the geographic range limit for all of the native woody plants that reach the edge of their range in the state. They constitute about half of the state's 240 species of native woody plants (McMahon *et al.* 1990, Boone and Krohn 2000). Light green lines are trees and shrubs that reach their northern limit in southern Maine, consistent with the southern growing season; dark green lines are trees and shrubs that reach their limit approximately along the Northern-Southern Interior climate divide.

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Climate Change and Bird Distribution Patterns

Of the 114 bird species currently in Maine, two species are likely to be lost and seven gained under moderate climate change predictions, versus a loss of 22 and a gain of 12 species under the most severe climate change (Matthews *et al.* 2004, Rodenhouse *et al.* 2008).

Future Distribution of the Black-capped Chickadee

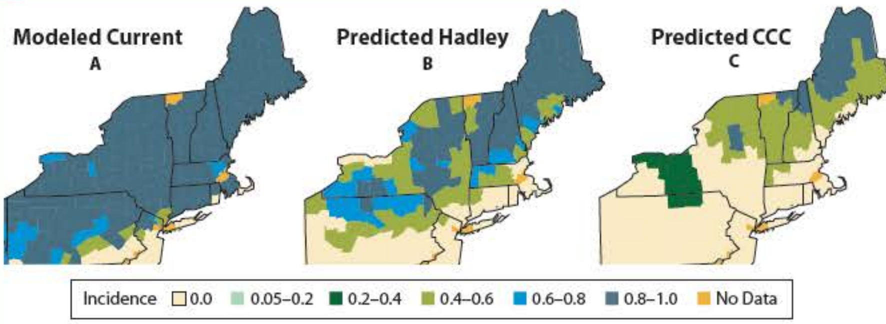

Figure 19 The black-capped chickadee, Maine's state bird, currently ranges from the Great Lakes east through New York and north throughout New England (a). Depending on the magnitude of climate change, the black-capped chickadee could become less widespread and less common in southern Maine (b), or could disappear from most areas except for western and northern Maine (c). Maps from Matthews *et al.* 2004.

These predictions are illustrated for the black-capped chickadee, Maine's state bird and a common bird from the Great Lakes east through New York and north throughout New England (*Figure 19*). Depending on the magnitude of climate change, the black-capped chickadee could become less widespread and less common in southern Maine (*Figure 19b*), or could disappear from most areas except for western and northern Maine (*Figure 19c*).

Northern species that are at the southern edge of their range in Maine, such as Canada lynx, purple lesser fritillary, Atlantic halibut, and giant rattlesnake plantain, could withdraw to the far reaches of the state or leave Maine entirely (see box, "Lynx and Marten" below). Some species that are confined to the highest altitudes, such as the Katahdin arctic butterfly, American pipit, Bicknell's thrush, and Lapland diapensia, could decline as our alpine ecosystems shrink or perhaps disappear.

Conversely, some southern species like chestnut oak and Virginia opossum might greatly expand their currently limited ranges in Maine while species from southern New England (*e.g.*, marbled salamander and summer flounder) could immigrate and become established in Maine if they can find suitable habitat for dispersal and colonization.

G. Shriver

Some of our most vulnerable ecosystems are also the rarest. Out of over 4,000 miles of coastline, Maine has only about 35 miles of sandy beach, where the endangered piping plover is already losing the competition with humans for undisturbed nesting beaches. Similarly, Maine's coast has only about 30 square miles of tidal salt marshes, which are home to many specialized species, including the salt marsh sharp-tailed sparrow that nests only a few centimeters above the peat and incoming tidewater. Both beaches and salt marshes are examples of coastal ecosystems at risk of disappearing due to sea-level rise.

Because there are so many pathways by which climate can influence a species and because each species has a unique niche or ecological role, every species will respond to climate change differently. One upshot of this complexity is that the groups of species that we often think of as forming a distinct, coherent ecological community such as spruce-fir forest or oak-pine forest may dissolve during climate change, leading to potentially novel communities that

The Future of Lynx and Marten

Both the American marten (Carroll 2007) and Canada lynx (Hoving *et al.* 2005, Gonzalez *et al.* 2007) travel easily in the snow. Martens hunt beneath the snow, and the lynx's long legs allow for movement through soft, deep snows. Both species occur in northwestern Maine, the part of the state with the greatest average annual snowfall. Wildlife biologists expect that once annual snowfall declines below some estimated threshold—270 centimeters per year (cm/yr or 106 inches) for lynx (Hoving *et al.* 2005) and 192 cm/yr (76 inches) for marten (Krohn *et al.* 1995)—these two species will decline and eventually disappear from the state, and will be replaced with two closely related but less snow-adapted species, the bobcat and the fisher.

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are compositionally and ecologically unlike any others we have known (Williams *et al.* 2007).

Overall, we will probably gain more species than we lose because the expansion of southern species is predicted to be greater than the contraction of northern species (Parmesan *et al.* 1999, Thomas and Lennon 1999). The species most likely to increase rapidly in the state, whether native or exotic to North America, are those that travel easily, are adapted to a variety of conditions, and reproduce fast—all characteristics of weedy or invasive species.

We have focused on how species respond to climate change by shifting their geographic ranges because this is the best documented type of response. However, organisms can also respond to climate change by altering their behavior, such as by foraging at different times of day (*e.g.*, when it is cooler), or by shifting their diets in response to climate-induced changes in available food resources. Some individuals may be better adapted genetically to the new conditions compared to others of the same species. Rapid evolutionary responses to warming temperatures, leading to an enhanced ability to survive and reproduce under warmer conditions, have been shown to occur in a variety of organisms, mainly those with short lifespans (Hendry and Kinnison 1999, Skelly *et al.* 2007). Although some species may be flexible enough to cope with climate change, long-lived species, and those with small population sizes, are less likely to be able to adapt fast enough to the predicted rate of change.

Biodiversity represents the reservoir of options that ecosystems have to respond to environmental change. Therefore, conservationists strive to protect Maine's entire native biota, especially focusing on rare and endangered species because they are already in the greatest jeopardy of disappearing (see list at the end of this section). The state's official list of endangered and threatened species will likely grow as a result of climate change. Species most likely to be added to the list include those at the extreme southern edge of their range, alpine species confined to shrinking islands of high-elevation habitat, and coastal species susceptible to ocean storm events and habitat inundation. Unfortunately, many of the species currently state-listed because they have a limited geographic range in southern Maine, (like the black racer snake, New England cottontail, and twilight moth), are quite specialized in their habitat requirements, or are not good candidates for dispersing through heavily developed landscapes, are unlikely to increase in population as a result of a warmer climate.

Most people are likely to consider the decline of any native species a negative consequence of climate change, and having high ecological, economic, or cultural value will add to the loss. In the worst case scenario, for species confined to Maine or a small portion of our region, extinction here could mean global extinction. Fortunately for most species, a decline in Maine may still leave them reasonably widespread and common in Canada, although having moose and loons in Quebec and not in Maine would be small consolation for Mainers.

Conversely, the prospect of southern species extending their ranges in Maine may or may not be viewed as a positive change. We are likely to accept native species with presumably benign or neutral effects such as Fowler's toads or Carolina wrens, but this does not apply to all species. Consider the prospect of having deer ticks (and the threat of Lyme disease) expanding to cover the whole state (see Health section). The idea of undesirable changes in Maine's biota comes to the fore dramatically when considering the potential impacts of exotic invasive species such as hemlock wooly adelgid (an invertebrate pest of hemlock capable of causing up to 90% mortality), Asiatic clam (a recent invader in southern New England lakes that competes with native mussels), or largemouth bass, a warm-water predator of native fishes.

Opportunities & Adaptation

Changes in climate are likely to exacerbate existing stresses, especially for species that are already under assault from issues such as habitat loss, contamination, and overharvesting. For example, brook trout populations are known to be greatly reduced in many watersheds of southern Maine, probably reflecting the action of multiple stressors in addition to climate change. Similarly, warming of the Gulf of Maine may join overfishing to further stress cod populations (see box, "Cod and Lobster," page 20). In short, while species have a long history of adapting to climate change, the potential for unprecedented *rates* of climate change coupled with existing human-induced stressors are likely to make the next few decades a very challenging period for many species.

As humans who share this landscape, what, if anything, do we do? Attempts to conserve species that are withdrawing from the state may ultimately be futile, but we should be reluctant to accept the argument that "we might as well give up on this species because it's disappearing as a result of climate change." It is often difficult to distinguish the role of climate change among all the factors that might contribute to the decline of a species and given a chance, some species might be able to adapt to a changing climate better than we would predict. Indeed, because the stresses imposed by a rapidly shifting climate are *not* within our direct control, we should intensify our efforts to reduce other sources of stress that *are* within our control, especially habitat loss.

Maintaining or restoring landscape-scale connectivity is a priority, because a landscape fragmented by roads, dams, and development presents a barrier to many species during the process of geographic range shift. Maine may be in a somewhat better position than many states in this respect because of our extensive forests and relatively low human population density. However, fragmentation is increasing here, too, as land development is far outpacing land conservation in many areas. Conserving a connected network of ecological reserves within a matrix of undeveloped land, such as working forests, offers the best chance of retaining a rich, if rapidly-changing, mixture of plants and animals.

Floods on the St. John River

One of Maine's most famous plant species and the only one federally listed as endangered is the Furbish lousewort. Its habitat is almost entirely limited to the banks of the St. John River, where almost every year spring thaws of river ice lead to major ice dams that scour the bank of the river as the meltwater pushes downstream. The lousewort colonizes the banks thus cleared of vegetation. Between scour events, alders grow up and begin to shade out the lousewort. Lousewort shares this narrow band of habitat and precarious balance between ice scour and succession with a host of other plants that are rare in Maine but well-adapted to these conditions. With less snow and milder winters, ice scour events will likely be less frequent. While those plants that grow on the cobbles and rock ledges of the river will probably persist, the lousewort and other species may disappear from the river banks as alders and other trees take over.

M. Hunter

Controlling the effects of invasive exotic species may be possible, especially if we can act before a population becomes well-established. Maine's effort to stem the expansion of Eurasian water milfoil and other invasive aquatic plants is a good example of what can be done with proactive management and policy.

Some people may propose assisting species to colonize new habitat, especially rare plants that do not disperse readily (Hunter 2007). For example, if the St. John flooding regime were no longer able to support Furbish lousewort (see box above), moving some plants to a similar river ecosystem on Quebec's Gaspé Peninsula could ensure their survival. Similarly, Maine might provide suitable habitat for some "climate refugees" from the south. However, translocating populations is a very expensive and ecologically risky undertaking (*e.g.*, a refugee could become a problematic invasive species) so such proposals should be very carefully examined before implementation, and unauthorized private initiatives should be prohibited.

Because we don't know how plants and animals will respond to climate change, it would be wise to use diverse, flexible, and adaptive approaches to conservation. We can start by incorporating the issue of climate change more explicitly into existing plans and programs, such as the State Wildlife Action Plan, Gulf of Maine Plan, Forest Legacy Program, Land for Maine's Future, State Conservation and Outdoor Recreation Plan, Natural Areas Program, Maine Coastal Program, and Beginning with Habitat.

Knowledge gaps

How will species shift in range and adapt in response to climate change? And what do these responses mean in terms of Maine's ecosystems and economy? There is surprisingly little known about a majority of Maine's species, including many of ecological and economic importance. These assessments are needed for both our existing biota and species that may move into the state, including exotic pathogens and parasites.

Ecosystem and species monitoring rarely receives the attention it deserves. We need increased and improved ecological monitoring, especially of relatively undisturbed ecosystems, such as those found in the state's system of ecological reserves, in order to better distinguish climate change effects from other stressors more under our control and to examine the efficacy of management actions. Maine could be a leader in this kind of research, because we have the intact ecosystems and large tracts of undeveloped land required to gain such knowledge.

Maine State Endangered, Threatened, and Special Concern Species at potentially elevated vulnerability to the effects of climate change

E = Endangered
T = Threatened
SC = Special Concern

Common Name	Scientific Name	State Status	Vulnerability Notes
Birds			
American pipit (breeding population only)	*Anthus rubescens*	E	Alpine tundra habitat at risk of decline or loss.
least tern	*Sterna antillarum*	E	Limited beach nesting habitat at risk of decline or loss due to rising sea levels.
roseate tern	*Sterna dougallii*	E	Few small, flat nesting islands at risk of rising sea levels; changing marine food supply.
piping plover	*Charadrius melodus*	E	Limited beach nesting habitat at risk of decline or loss due to rising sea levels; increased nest flooding likely.
Arctic tern	*Sterna paradisaea*	T	Limited nesting islands at risk of rising sea levels; changing marine food supply.
Atlantic puffin	*Fratercula arctica*	T	Limited nesting islands at risk of rising sea levels; changing marine food supply.
great cormorant (breeding population only)	*Phalacrocorax carbo*	T	Limited nesting islands at risk of rising sea levels; changing marine food supply.
razorbill	*Alca torda*	T	Limited nesting islands at risk of rising sea levels; changing marine food supply.
Leach's storm-petrel	*Oceanodroma leucorhoa*	SC	Limited nesting islands at risk of rising sea levels; changing marine food supply.
Bicknell's thrush	*Catharus bicknelli*	SC	Subalpine spruce-fir habitat islands likely to decline; Northeast endemic.
rusty blackbird	*Euphagus carolinus*	SC	Northern wetland species at extreme southern edge of range.
Nelson's sharp-tailed sparrow	*Ammodramus nelsoni*	SC	Saltmarsh nesting habitat at risk of inundation with rising sea levels.
salt marsh sharp-tailed sparrow	*Ammodramus caudacutus*	SC	Salt marsh nesting habitat at risk of inundation with rising sea levels.
Mammals			
Northern bog lemming	*Synaptomys borealis*	T	Alpine tundra and boggy forest species at southern edge of range.
Canada lynx	*Lynx canadensis*	SC	Northern forest species at southern edge of range; lower snow depths may reduce habitat and increase competition.
Fish			
redfin pickerel	*Esox a. americanus*	E	Low-gradient coastal stream inhabitant potentially subject to habitat loss as sea levels rise and saline conditions ascend stream networks.
Arctic charr	*Salvelinus alpinus*	SC	Inhabits cold-water, oligotrophic lakes; Maine populations at southern edge of range.
lake whitefish	*Coregonus clupeaformis*	SC	Inhabits cold-water, oligotrophic lakes; Maine populations at southern edge of range.
Invertebrates			
Roaring Brook mayfly	*Epeorus frisoni*	E	Restricted to cold, high elevation streams; Northeast endemic.
unnamed mayfly	*Baetisca rubescens*	SC	Rare species restricted to cold, high elevation streams.
unnamed mayfly	*Ameletus browni*	SC	Rare species restricted to cold, high elevation, first-order streams; Northeast endemic.
Katahdin arctic butterfly	*Oenis polixenes katahdin*	E	Alpine tundra habitat at risk of decline or loss; Maine endemic.
purple lesser fritillary butterfly	*Boloria chariclea grandis*	T	Boreal forest species at extreme southern edge of range.
Frigga fritillary butterfly	*Boloria frigga*	SC	Sub-boreal peatland species at extr eme southern edge of range.
Canada whiteface dragonfly	*Leucorrhinia patricia*	SC	Boreal peatland species at extreme southern edge of range.
Quebec emerald dragonfly	*Somatochlora brevicincta*	SC	Northern peatland species at southern edge of range.
sedge darner dragonfly	*Aeshna juncea*	SC	Northern species of boggy ponds and peatlands at extreme southern edge of range.
salt marsh tiger beetle	*Cicindela marginata*	SC	Coastal mud and sand flats used for breeding at risk of inundation and decline with rising sea levels.

* This list is the outcome of a 'rapid assessment' based primarily on habitat associations—rather than an in-depth review that considers reproductive biology, population viability, etc. It is also an assessment of the risk of loss from Maine, rather than extinction globally.

Common Name	Scientific Name	State Status	Vulnerability Notes
Plants			
Aleutian maidenhair fern	*Adiantum aleuticum*	E	Disjunct and at southern end of range in northeastern US.
Nova Scotia false-foxglove	*Agalinis neoscotica*	T	Southern edge of range.
boreal bentgrass	*Agrostis mertensii*	T	Alpine, southern edge of range.
small round-leaved orchis	*Amerorchis rotundifolia*	T	Southern edge of range.
cut-leaved anemone	*Anemone multifida*	T	Rivershore, southern edge of range.
alpine bearberry	*Arctostaphylos alpina*	T	Alpine, southern edge of range.
hairy arnica	*Arnica lanceolata*	T	Rivershore and sub-alpine, southern edge of range.
green spleenwort	*Asplenium trichomanes-ramosum*	E	Southern edge of range.
tundra dwarf birch	*Betula glandulosa*	E	Southern edge of range.
dwarf white birch	*Betula minor*	E	Southern edge of range.
Pickering's reed bent-grass	*Calamagrostis pickeringii*	T	Southern edge of range.
Northern reed grass	*Calamagrostis stricta ssp inexpansa*	E	Southern edge of range.
neglected reed-grass	*Calamagrostis stricta ssp stricta*	T	Southern edge of range.
alpine bitter-cress	*Cardamine bellidifolia*	E	Alpine, southern edge of range.
Long's bitter-cress	*Cardamine longii*	T	Tidal marsh.
intermediate sedge	*Carex norvegica*	E	Southern edge of range in the east.
Orono sedge	*Carex oronensis*	T	Endemic.
variable sedge	*Carex polymorpha*	E	Small, fragmented habitat.
Russett sedge	*Carex saxatilis*	E	Alpine, southern edge of range.
brackish sedge	*Carex vacillans*	E	Tidal marsh.
Alaskan clubmoss	*Diphasiastrum sitchense*	T	Alpine, southern edge of range.
rock whitlow-grass	*Draba arabisans*	T	Mountain tops, southern edge of range.
lance-leaved draba	*Draba cana*	E	Mountain tops.
rock whitlow-grass	*Draba glabella*	E	Southern edge of range.
English sundew	*Drosera anglica*	E	Southern edge of range.
slender-leaved sundew	*Drosera linearis*	E	Southern edge of range.
male fern	*Dryopteris filix-mas*	E	Southern edge of range in the east.
alpine willow-herb	*Epilobium anagallidifolium*	E	Alpine, southern edge of range.
Hornemann's willow-herb	*Epilobium hornemannii*	E	Alpine, southern edge of range.
Oakes' eyebright	*Euphrasia oakesii*	E	Alpine, southern edge of range.
Arctic red fescue	*Festuca prolifera*	E	Alpine, southern edge of range.
boreal bedstraw	*Galium kamtschaticum*	T	Southern edge of range.
Northern gentian	*Gentianella amarella*	E	Southern edge of range.
giant rattlesnake-plantain	*Goodyera oblongifolia*	E	Southern edge of range in the east
moss bell-heather	*Harrimanella hypnoides*	T	Alpine, southern edge of range.
Robinson's hawkweed	*Hieracium robinsonii*	E	Rivershore, southern edge of range.
alpine sweet-grass	*Hierochloe alpina*	T	Alpine, southern edge of range.
alpine clubmoss	*Huperzia selago*	T	Southern edge of range.
slender blue flag	*Iris prismatica*	T	Tidal marsh.
prototype quillwort	*Isoetes prototypus*	T	Limited to Northern New England & Maritime Provinces.
marsh-elder	*Iva frutescens*	E	Tidal marsh.
slender rush	*Juncus subtilis*	T	Southern edge of range.

Common Name	Scientific Name	State Status	Vulnerability Notes
Plants			
Lilaeopsis	*Lilaeopsis chinensis*	T	Tidal marsh.
auricled twayblade	*Listera auriculata*	T	Southern edge of range.
alpine azalea	*Loiseleuria procumbens*	T	Alpine, southern edge of range.
marsh felwort	*Lomatogonium rotatum*	T	Southern end of range.
Northern wood-rush	*Luzula confusa*	E	Alpine, southern edge of range.
spiked wood-rush	*Luzula spicata*	T	Alpine, southern edge of range.
Arctic sandwort	*Minuartia rubella*	E	Southern edge of range in the East.
pygmy water-lily	*Nymphaea leibergii*	T	Southern end of range.
alpine cudweed	*Omalotheca supina*	E	Alpine, southern edge of range.
St. John oxytrope	*Oxytropis campestris*	T	Rivershore, southern edge of range.
silverling	*Paronychia argyrocoma*	T	Mountain tops and rivershores.
Furbish's lousewort	*Pedicularis furbishiae*	E	Endemic to shores of St. John River in Maine and New Brunswick.
alpine bistort	*Persicaria vivipara*	E	Alpine, southern edge of range.
mountain timothy	*Phleum alpinum*	T	Rivershore, southern edge of range.
mountain heath	*Phyllodoce caerulea*	T	Alpine, southern edge of range.
common butterwort	*Pinguicula vulgaris*	E	Alpine, southern edge of range.
prairie white-fringed orchid	*Platanthera leucophaea*	E	Rare throughout range, single disjunct population in northern Maine.
wavy bluegrass	*Poa fernaldiana*	E	Alpine, southern edge of range.
white bluegrass	*Poa glauca*	T	Southern edge of range in the East.
Boott's rattlesnake root	*Prenanthes boottii*	E	Alpine, southern edge of range.
dwarf rattlesnake root	*Prenanthes nana*	E	Alpine, southern edge of range.
small yellow water crowfoot	*Ranunculus gmelinii*	T	Southern edge of range in the East.
Lapland buttercup	*Ranunculus lapponicus*	T	Southern edge of range.
Lapland rosebay	*Rhododendron lapponicum*	T	Alpine, southern edge of range.
stiff arrow-head	*Sagittaria rigida*	T	Tidal in part.
Arctic willow	*Salix arctophila*	E	Alpine, southern edge of range.
dwarf willow	*Salix herbacea*	T	Alpine, southern edge of range.
blue-leaf willow	*Salix myricoides*	T	Southern edge of range.
tea-leaved willow	*Salix planifolia*	T	Alpine, southern edge of range.
bearberry willow	*Salix uva-ursi*	T	Alpine, southern edge of range.
star saxifrage	*Saxifraga foliolosa*	E	Alpine, southern edge of range.
low spike-moss	*Selaginella selaginoides*	T	Southern edge of range.
Cutler's goldenrod	*Solidago multiradiata*	T	Alpine, southern edge of range.
American sea-blite	*Suaeda calceoliformis*	T	Tidal marsh.
Anticosti aster	*Symphyotrichum anticostense*	E	Rivershore, southern edge of range.
small salt-marsh aster	*Symphyotrichum subulatum*	E	Tidal marsh.
mountain hairgrass	*Vahlodea atropurpurea*	E	Alpine, southern edge of range.
alpine speedwell	*Veronica wormskjoldii*	E	Alpine, southern edge of range.
alpine marsh violet	*Viola palustris*	E	Alpine, southern edge of range.
Northern woodsia	*Woodsia alpina*	T	Southern edge of range, mountain tops.
smooth woodsia	*Woodsia glabella*	T	Southern edge of range, mountain tops.

Indigenous Peoples

Team Leader John Daigle

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A strong and multifaceted dependence on natural resources makes indigenous populations around the world, and in Maine, particularly vulnerable to climate change.

Maine's four recognized Wabanaki tribes face geographical range changes of plant and animal species, and a potential loss of traditional resources, affecting tribal culture, economies, and government budgets.

The livelihoods of Maine's indigenous peoples may very well depend on their abilities to help shape new economies and sustainable development, including decisions on natural resource management.

Photo courtesy Penobscot Indian Nation

Brown ash Decrease in number of basket quality trees caused by damaging periods of drought and loss of protective snow cover is also threatened by an invasive species pest called the emerald ash borer, bringing fear to the Wabanaki people of losing a vital link to their ancestral ways.

The Intergovernmental Panel on Climate Change recognizes that indigenous peoples of North America and those who are socially and economically disadvantaged are disproportionately vulnerable to climate change (Field *et al.* 2007). Although our focus here is on indigenous peoples of Maine, the potential effects of climate change are highly applicable and relevant to other residents in the state.

Climate and indigenous peoples

Four tribes make up the indigenous peoples of Maine and have been allied for centuries in the Wabanaki Confederacy. Wabanaki means People of the Dawn, or East, and includes the Penobscot Nation, Passamaquoddy Tribes, Houlton Band of Maliseet Indians, and the Aroostook Band of Micmacs. All are federally recognized, with similar yet distinct languages and cultures.

> Glooskap came first of all into this country, into the land of the Wabanaki, next to sunrise. There were no Indians here then. And in this way he made man: He took his bow and arrows and shot at trees, the basket trees, the ash. Then Indians came out of the bark of the ash tree.
>
> — Wabanaki Creation Story

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Many important Wabanaki stories including the "creation story" are tied to specific natural features of the landscape. Modern Wabanaki artists continue to use birch bark from the forests, brown ash from the river banks, and sweetgrass from the salt marshes to create distinctive traditional arts. The plants and wildlife are still utilized for subsistence as well as for other important socio-cultural functions such as spiritual enlightenment, family bonding, and learning traditional lifeways.

Many indigenous communities in northern Canada and Alaska are already experiencing constraints on lifestyles and economic activity from less reliable sea and lake ice (for traveling, hunting, fishing, and whaling), loss of forest resources from insect damage, stress on caribou, and more exposed coastal infrastructure from diminishing sea ice (Field *et al.* 2007). It is believed that the strong and multifaceted dependence on natural resources that make indigenous populations as a whole particularly vulnerable to climate change will be highly applicable to the indigenous peoples of Maine. According to Houser *et al.* (2001), approximately 1.2 million (60%) of US tribal members live on or near reservations, and many pursue lifestyles with a mix of traditional subsistence activities and wage labor. Maine wild foods such as fiddleheads, deer, moose, birds, fish, berries, and seafood provide not only sustenance but cultural connections through storytelling, harvesting, processing, and sharing of food sources.

Bonnie Newsom

Picking sweetgrass Sea-level rise and human development along the coast may impact opportunities for the Wabanaki people to collect sweetgrass utilized for fancy baskets and tribal ceremonies.

Some of the specific threats to indigenous peoples of Maine inherent in climate change scenarios involve the potential loss of traditional resources and geographical range changes of plant and animal species. For example, moose populations are likely to be affected by an increase in ticks as well as less than optimal habitat conditions. Rising sea levels may endanger Native American coastal middens or damage Wabanaki coastal petroglyph sites. Coastal lands likely will continue to be highly attractive and potential for housing development both on the coast and inland will lead to further land-use changes that may restrict access to traditional resource gathering areas.

Many reservation economies and budgets of indigenous governments depend heavily on agriculture, forest products, and tourism. The availability and access to birch, brown ash, and sweetgrass, utilized by the indigenous peoples of Maine for making fancy baskets and other artistic works, are an important component within the tourism industry. However, climate change is expected to affect tree health due to two major processes: damage to tree tissues resulting in diebacks and declines, and increased survival of tree pests due to warmer winter temperatures. Maine's current climate of abundant moisture throughout the year predisposes trees to drought damage. This occurs when trees can regenerate on sites that have enough moisture in normal years but inadequate moisture during drought extremes. Such a situation occurred with brown ash (or black ash, *Fraxinus nigra*) when a "100-year" drought in May 1985 and 1987 resulted in severe dieback in trees growing on sites where high water tables resulted in shallow rooting (Livingston 2008). Future scenarios predict more frequent drought cycles that may further magnify this relationship and reduce future availability of brown ash (Prasad *et al.* 2007).

Opportunities & Adaptation

For indigenous peoples around the world, climate change brings different kinds of risks and threats to cultural survival, and undermines indigenous human rights (IWGIA 2008). As illustrated above, the consequences of ecosystem change have potential implications to indigenous peoples of Maine for the use, protection, and management of wildlife (*e.g.*, moose), fisheries (*e.g.*, Atlantic salmon), and forests (*e.g.*, brown ash), that may affect customary uses of culturally and economically important species.

Part of the risk assessment that specifically identifies indigenous peoples as being disproportionately vulnerable to climate change are other issues faced such as political and economic marginalization, loss of land and resources, human rights violations, discrimination, and unemployment. Native Americans historically have suffered higher mortality rates as a result of epidemics such as influenza, smallpox, measles, and diphtheria. Climate change is projected to directly and indirectly

Economic and Health Disparities

Compared to all of the state's population, Maine's indigenous peoples:

- have lower per capita incomes ($12,700 versus $19,727);
- experience higher rates of unemployment (on average double—14.4% versus 6.6%);
- drop out of school at higher rates and attain higher education at lower rates (more than 50% fewer complete a degree once starting college as compared to other Maine students);
- experience higher rates of teen births (on average much higher and nearly doubled within the 1993-1997 time period to 67.1% as compared to 34.1%);
- die at a younger age (on average 60 years old versus 74 years old for all Mainers);
- may die at higher rates from cancer, particularly lung cancer; and
- experience higher rates of tobacco addiction, problem alcohol use, and obesity.

Barriers to health identified by Maine tribal health directors include transportation; low income; prejudice and racism; shortages of qualified health personnel; inadequate state and federal funding; lack of access and/or culturally appropriate health care, especially for substance abuse treatment and nursing home care; threats from environmental toxics such as dioxin, mercury, lead, arsenic, and cadmium; and inadequate public policy, in part due to an absence of voting representation in the Maine legislature.

(Kuenhnert 2000, Mills 2002)

promote the mutation and spread of pathogens responsible for epidemic diseases. Significant economic and health disparities exist between the indigenous peoples of Maine and all of Maine's population (see box above). Climate change will likely magnify these existing problems and this in turn will likely influence adaptive capacity of the indigenous peoples of Maine.

Indigenous peoples worldwide are vital to, and active in, the many ecosystems of their lands and territories and may therefore help to enhance the resilience of these ecosystems (IWGIA 2008, UNPFII 2008). This is critically vital as most of the plant and animal species diversity is located predominantly in these natural environments where indigenous populations co-exist. Wabanaki ancestors have lived in and around Maine for more than 12,000 years and have exhibited resilience to changes in their local climate. Wabanaki people have survived mass immigration, economic destitution, environmental degradation, and political, social, and cultural domination. Some of indigenous peoples' contemporary solutions may help society at large to cope with impending changes.

In North America, some indigenous groups are striving to cope with climate change by focusing on the economic opportunities that it may create (IWGIA 2008, UNPFII 2008). For example, the increased demand for wind and solar power could make tribal lands an important source of renewable energy. This has been explored by indigenous peoples of the western and midwestern US, and could be done in Maine. In addition, opportunities exist for carbon sequestration with tribal forest lands in Maine, as well as with increases in summer tourism potential as other parts of the country become warmer. Ultimately, lessons and approaches undertaken by the indigenous peoples of Maine may contribute to efforts being made by indigenous peoples worldwide.

Despite being among the most affected by climate change, indigenous peoples' rights and concerns in most parts of the world have so far been almost silent in the climate change discussions and solutions proposed at the national, regional, and international level (IWGIA 2008, UNPFII 2008). It will be important to examine closely any legal or institutional barriers that may inhibit involvement of indigenous peoples of Maine in decision-making processes as well as design and implementation of initiatives to address climate change. The livelihoods and cultures of the indigenous peoples of Maine may very well depend on their abilities to participate and provide input in the shaping of the new forms of economies and sustainable development, including decisions on management of natural resources.

Indigenous peoples are spiritually and culturally invested in specific areas of Maine and many of their values, meanings, and identities are closely interlinked with features of the natural landscape and physical interactions with that landscape. Potential ecosystem responses to climate change may alter livelihoods and traditions of indigenous peoples in Maine and may require monitoring of certain social pathological phenomena such as anomie that is sometimes associated with rapid and profound cultural changes in society. Additional financial resources will be necessary to assist with adaptive capacity and mitigation scenarios for the potential responses to climate change.

Combinations of public policy (national security, health) and climate changes may further challenge indigenous peoples of Maine. Increasing restrictions on the US-Canadian border have been problematic for indigenous peoples, hampering access to traditional hunting and gathering areas and maintaining connections with relatives on both sides of the border. As noted previously, culturally significant plant and animal species will likely migrate northward and near the international boundaries of Maine and Canada. The fragmentation of communities due to border restrictions, economic reasons in part related to availability and access to natural resources, may negatively result in further loss of language and cultural identity.

Challenges still exist in the recognition and application of indigenous knowledge systems. How this might be recognized and applied in Maine as we move forward seems critical for success, and this cooperative endeavor may ultimately be a showcase for others to learn from around the world. Indigenous human culture in Maine must be considered one of our most precious natural resources. It should be protected, fostered, and supported in a manner commensurate with its high value.

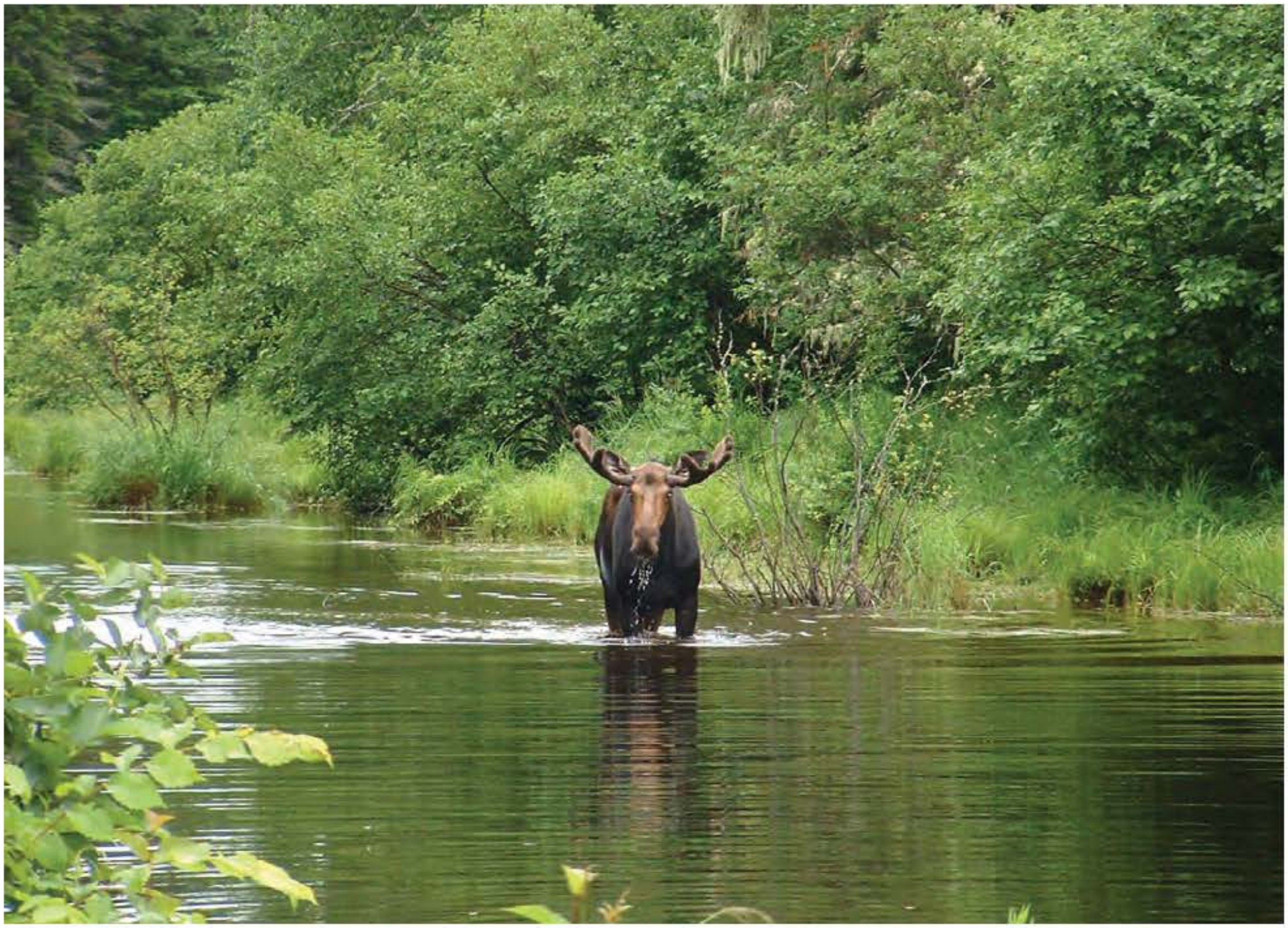
Knowledge gaps

Projections of climate change still have important uncertainties regarding the range of effects on ecosystems and specifically the frequency and amounts of precipitation as compared to temperature (Christensen *et al.* 2007). For example, will increased precipitation and other climate-related changes exacerbate health-related concerns with mercury and other harmful air pollutants that interfere with people's ability to consume freshwater fishes?

A better understanding of the stressors of climate change and interrelationships with land-use changes are important. For example, the health of brown ash is dependent on a number of factors such as human utilization levels, tree disease, and hydrology modifications as a result of dams and other human development. Opportunities exist to better understand these effects, especially on hydrological influences with dams planned for removal on lower portions of the Penobscot River. Finally, more research is needed on culturally significant animal species as well as other important plant species such as fiddleheads and sweetgrass.

Most of the current climate change research focuses on impacts to single sectors (*e.g.*, tourism, wildlife, forests, health). More studies are needed to address the interacting responses of diverse sectors to climate change. As illustrated above, the indigenous peoples of Maine have complex and intertwined relationships with multiple sectors. A better understanding of these relationships and culturally compatible ways of communicating this information will improve adaptive capacity and mitigation scenarios.

What is the level of adaptive capacity and mitigation most helpful to the indigenous peoples of Maine? There are important lessons to be learned from indigenous peoples of the polar region and other parts of the world where the magnitude of change caused by climate change is most prevalent (UNPFII 2008).



Tom Desjardin

Moose An iconic species of Maine – moose are likely to be negatively impacted by tick populations with social, cultural, and economic implications to Wabanaki people and residents of Maine as well as the tourism-related branding and visitor viewing opportunities.

IV SECTOR ISSUES & OPPORTUNITIES

Agriculture

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Tim Griffin

The plant hardiness zones used by farmers and gardeners have shifted north, allowing Mainers to grow crops, plants, and flowers previously available only in warmer climes. Warmer temperatures will give farmers and the horticulture industry continued access to new crops and livestock.

Farmers and gardeners can expect a greater need for irrigation, particularly for high value crops, to offset increased soil moisture loss through evaporation and transpiration. Increasing temperatures will also negatively affect confined livestock in the state.

New pests, invasive plants, and pathogens will increasingly encroach into Maine, threatening plants, animals, and humans, and making management more difficult.

Agriculture is a diverse industry, contributing over $1 billion annually to Maine's economy. Although agriculture has undergone significant consolidation in the US over the past 40 years, farming in Maine is still dominated by small to moderate-sized, family-owned farms, with major products including dairy, potatoes, grains, vegetables and fruits, wild blueberries, and ornamental and turf products.

This industry, like other natural resource-based industries in Maine, faces substantial effects from projected increases in temperature and shifts in the amount and distribution of precipitation. In addition to factors like soil texture and management inputs, temperature and precipitation are two of the driving forces controlling the productivity and, ultimately, the viability of agriculture in Maine. This includes both direct effects (like the effect of higher temperature on current or potential crops) and indirect effects (changing pest pressure, for example).

Climate and agriculture: direct and indirect effects

Increasing temperature affects the length of the crop growing season and frost-free periods. Amounts and patterns of precipitation determine the amount of water available in the soil.

But agricultural systems can also be affected directly by increasing atmospheric CO_2 concentration. The "CO_2 fertilization effect" is an increase in plant biomass or yield resulting from increased CO_2 concentration in the air, which increases a plant's photosynthetic rate and water use efficiency. CO_2 concentrations of 550-600 ppm (which is predicted under the IPCC's B1 scenario) have been shown to increase plant biomass up to 35% (Long *et al.* 2004), although an increase of 12-15% is probably more realistic. The CO_2 effect is particularly striking for cool-season crops, of which Maine has many: potatoes, oats, barley, lettuce, broccoli, strawberries. In addition to enhanced growth, some evidence suggests that plants under these conditions may be moderately more drought-tolerant.

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One consistent plant response to increasing CO_2 levels is a reduction in protein concentration in the plant (Idso and Idso 2001, Taub *et al.* 2008), which has clear implications for both human and animal nutrition. Potentially serious and unpredictable effects, such as how plants defend themselves against insects and other pests, could result as plant chemistry changes in response to CO_2 concentrations.

Maine farms in the future

All plants respond to temperature. A plant's growth rate generally increases up to some optimum temperature (or range), and then declines with further warming. Different crops have different optima, which means that the effect of warming will not be the same for all of the crops that are grown (or could be grown) in Maine. Potatoes have a relatively low temperature optima (15-18°C/60-64°F; about the growing season average for Presque Isle), and projected temperature increases would result in common yield reductions of 25-35%. Some cool-season grains would be affected in a similar way, although these losses can be moderated by changes in cultural practices like planting date. Other vegetable crops, like tomatoes and pumpkins, have temperature optima of 25°C (77°F) or above, so in some parts of Maine, projected temperatures would be moving *towards*, not away from, their optimal range. An optimum temperature range of 30-35°C (86-95°F) makes warm-season grasses like corn currently challenging to grow in Maine; these crops would benefit from both higher temperatures and a longer growing season (depending on related changes in precipitation). Warmer temperatures will give farmers access to a broader range of hybrids or cultivars for many crops.

Winter temperatures, which may increase more rapidly than growing season temperatures in some parts of Maine, will affect a broad range of perennial crops, from the forage grasses and legumes grown on dairy farms to tree fruits and wild blueberries. Winter warming can negatively influence perennials in several ways. First, warm periods during the winter may be sufficient to deacclimate these plants, causing them to lose their winter hardiness. Subsequent cold weather increases the likelihood of winter injury or winterkill (Bélanger *et al.* 2002). Second, a number of crops benefit from the consistent insulation provided by snowpack. If winter warming reduces (or eliminates) the snowpack, or results in the formation of ice sheets, severe winterkill is likely. Warming in winter and during the growing season will also shift the timing of significant developmental events (like bud break and flowering) for tree fruit and other crops. Wolfe *et al.* (2005) have already documented that leaf and flower emergence of lilac, apple, and grape shifted two to eight days earlier in the spring during the period from 1965 to 2001. These changes are similar to those shown by Chmielewski *et al.* (2004) in Europe. While the US Department of Agriculture has not yet revised the official plant hardiness zones, the Arbor Day Foundation (2006) released new maps in 2006 (*Figure 20*).

Even if precipitation during the growing season is uniformly distributed, less water will be available for plants, because the higher temperatures will result in greater transpiration (loss of water from the plants) and evaporation (from soil). The more frequent, high-intensity rainfall events predicted for the future are less effective at replenishing soil water supplies and more likely to erode soil. Crops that complete their development and set yield during the summer months (including high-value wild blueberries and potato) will be severely affected if irrigation is not available.

Agricultural pests, including insects, weeds, viruses, and other pathogens, are serious threats. Like crops, weeds respond to increasing CO_2 concentration, and could gain advantage over associated crops. Higher temperatures increase development rates of insects, just as they do for plants, and this can alter plant-pest interactions in several ways (Ward and Masters 2007). Current pests like the Colorado potato beetle, which completes one full generation per season in Maine under current conditions, may complete multiple generations under warmer temperatures and a longer growing season, increasing potential crop damage *and* the cost of control

Maine Hardiness Zones, 1990 and 2006

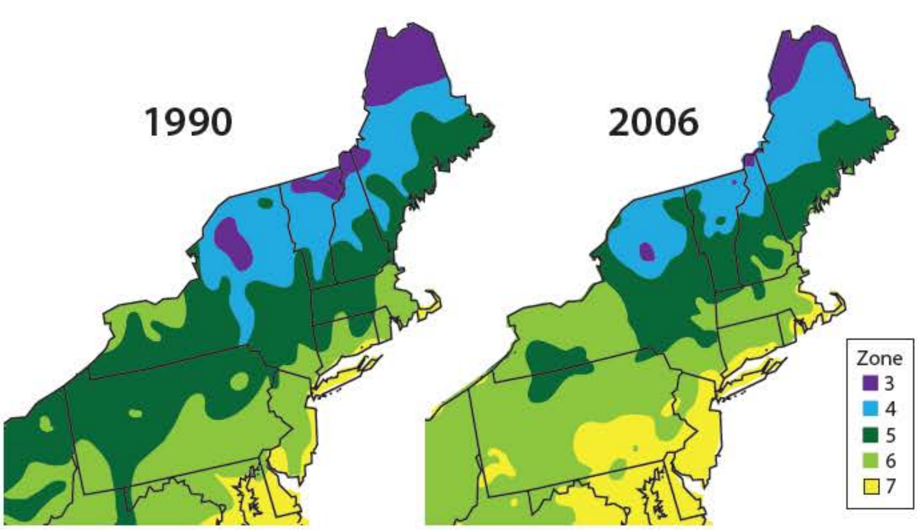

Figure 20 The Arbor Day Foundation (2006) revised plant hardiness zones used by farmers and gardners, based on data from 5,000 National Climatic Data Center cooperative stations across the continental United States. A northward shift in zones reflects a warming climate.

strategies. Multiple generations of this pest already occur in Massachusetts and Connecticut.

With warmer temperatures, new pests will arrive and survive in Maine. For example, the blueberry gall midge, which has been a problem in southern areas like New Jersey, is already affecting wild blueberries in eastern Maine. Moderating winter temperatures, especially in coastal and southern Maine, also increase the likelihood that pests that are currently migratory and thus sporadic in Maine could successfully overwinter here; for example, many aphid species arrive with storm fronts from the south each year (aphids are primary vectors for many plant viral diseases). While there is a possibility that natural predators and the activity of beneficial insects may also increase, most of these potential changes in plant pests suggest increased use of pesticides, which carries economic, environmental, and human health implications.

Scott Bauer

The effects of increasing temperatures are largely negative for animal agriculture in the state. As pointed out by Wolfe *et al.* (2008), a few days of high temperatures (and humidity) have a prolonged impact on productivity or output, and semi-confined animals like dairy cows already experience periods of heat stress. In simulations of the higher emission scenarios, Wolfe *et al.* (2008) noted the heat stress would be prevalent throughout most areas of Maine (and the Northeast), except for perhaps the northern part of Maine. As the cumulative amount of time under even moderate heat stress increases, productivity declines, reproductive function may be compromised, and the incidence and severity of infections like mastitis (an udder infection of dairy cows) increases. Increased temperature and precipitation also present a challenge to farmers in managing feedstocks on their farm. Feed stored in silos can spoil where it is exposed to air and humidity, and feed degrades more rapidly in warmer temperatures.

Higher winter temperatures, a greater proportion of rainfall to snow, and more frequent high-intensity events all result in wetter or muddier conditions, which contribute directly to animal stress and may also increase populations of organisms responsible for mastitis. For cattle in particular, this increased stress level contributes to respiratory infections (pneumonia).

Opportunities & Adaptation

A warmer growing season represents an opportunity for crop agriculture in Maine. Farmers will have access not only to new crops that are not currently viable here, but also to a broader genetic base for current crops. The likelihood that energy prices will increase in the future adds to this opportunity; about 71 million people currently live within a day's drive of Maine, and transportation costs may make cross-continental (or international) movement of food cost prohibitive.

Agriculture can also play a significant role in the mitigation of climate change, as soil is a large potential sink for carbon. No-till and low-tillage agriculture, reduced use of inorganic nitrogen fertilizers, legume-based cover cropping strategies, and on-farm composting all reduce greenhouse gas emissions from agriculture. The increasing prevalence of farmers markets, community supported agriculture (CSAs), and wholesale and retail outlets relying on locally produced foods also can reduce the greenhouse gas contributions of food production and can increase food quality.

Several prospects temper these opportunities. First, crop production will require more inputs; as noted previously, pesticide inputs will likely increase and the reliance of agriculture on petroleum remains a vulnerability. Second, the infrastructure and supporting industries (including input retailers, marketing, and processing) have been shrinking in Maine for decades as the physical footprint of farming has gotten smaller. Crop acreage in Maine has fallen from 600,000 to 250,000 acres in the last 40 years. It is not realistic to expect that Maine can take advantage of any opportunities that climate change may present without a concurrent investment in infrastructure, including protecting farmland from development.

A recent report from the USDA Forest Service (*Figure 21*; White and Mazza 2008) identifies portions of Maine that are expected to experience significant residential expansion. This report is relevant to farmland since agriculture and forest are intertwined throughout the state, as most farms include forest acreage.

Water availability can be manipulated to some extent by management techniques, but increased irrigation capacity will be a necessity for many sectors of the agricultural industry in Maine, particularly for high-value crops. Groundwater is used to a limited extent for irrigation in Maine, and withdrawals are replenished by precipitation and snowmelt before the next season. Reduced precipitation inputs and increased evapotranspiration may result in long-term depletion of some aquifers. Where groundwater is not a feasible source of irrigation water, constructed impoundments (ponds) will be needed, requiring significant investment. Withdrawing water from streams and rivers during the growing season will likely be a less prominent source of irrigation because of regulation and habitat protection concerns.

Transitional issues like crop selection or modification of specific production practices are extensions of what Maine farmers have been doing for generations. There are, however, several areas where farmers will likely have to make changes that require capital expenditures. For example, increased temperatures can be managed on dairy farms by either modifying existing buildings to provide better ventilation and cooling, or constructing new facilities. This is clearly expensive, and larger farms may find it easier to capitalize on these changes than smaller farms. The same could be said of orchards: if climate change results in current apple varieties becoming less viable, replacement represents a very large investment.

Public policy and investment can reduce the negative economic impact of these types of changes, and ease the transition. Educational programs and research on short-term adaptation is critical, including in such areas as crop adaptation and changes in crop management. Medium-term infrastructure improvement, including the development and refinement of irrigation, could be aided by cost-share agreements, as they have been in the past. Assuring long-term access to both land and water resources requires clarification and extension of existing policy.

Knowledge gaps

What are the potential effects of increased temperatures on the diverse mix of crops and animals produced in Maine? For example, the interactions among the components of climate change (this includes temperature, water, and CO_2 concentration) are complex, and much of the research to date deals with single factors or components.

What are the estimated costs of replacing infrastructure and building flexible capacity for changing crops?

Tim Griffin

Forest Products

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Rob Lilieholm

As the world's population grows larger and wealthier, pressure will increase on forest resources for sustainable building materials, furniture, paper, and energy.

A significant factor affecting the industry will be the rate and magnitude of climate change, and how these changes influence the adoption of new technologies and resulting product mix.

Development pressure reduces the land base available for Maine's natural resource industries, limiting their ability to expand and adapt. Development also reduces carbon stored on the landscape in forests, wetlands, and other ecosystems, adding to greenhouse gas emissions.

Forests have been a pillar of Maine's economy for over 200 years. Today, Maine's forest products sector includes 90,000 private forestland owners, about 2,500 logging and hauling service providers, and roughly 300 primary forest products processors collectively engaged in the growing, harvesting, transporting, and processing of an array of forest products (McWilliams *et al.* 2005, McBride *et al.* 2008). These products range from pulp and paper, hardwood and softwood lumber, and various wood composites and panel products, to specialty items like dowels and tool handles, and an increasing interest in energy products like wood pellets and cellulosic ethanol (Benjamin *et al.* 2009).

Overall, forest-based manufacturing is Maine's largest manufacturing sector, contributing $5.31 billion or roughly 36% of the state's manufacturing sales (NEFA 2007). With direct employment of nearly 20,000 people and a payroll of $750 million, the forest industry is the largest employer in Maine's manufacturing sector and, with wages at roughly twice the state average, serves as the lifeblood of many Maine communities.

Climate and the forest products industry

By directly influencing the geographic distribution, health (tree quality and growth rate), and species composition of forests, climate indirectly influences the likely products from the forest.

As described in the forest ecosystems section of this report, forest growth rate is expected to increase, which would positively affect the industry. In particular, the solid wood and building materials sectors would benefit from increasing growth of traditional high-value species like white pine and aspen. However, this simplified view assumes that species and product mix do not change, an unlikely scenario as the mix of species, and species diversity within forest types, are expected to change.

In addition to the types of trees, climate change also may affect overall wood availability and will certainly change the timing of forest operations. For example, a longer mud season and shorter periods of hard freeze would restrict the harvesting season.

If climate change results in increased susceptibility to insects and disease, the resulting growth losses and dieback could profoundly affect the industry. Larger shifts in species composition could spur massive areas of die-off, with stumpage prices plummeting as salvaged dead and dying timber overwhelms the logging sector and floods local markets, and forestland owners struggle to coordinate salvage operations, deal with fire protection issues, and accelerate reforestation schedules. The combination of low stumpage values and increased management costs would harm landowners while favoring processors, at least in the short term. Particularly vulnerable are mills that depend on one or a few species, such as mills producing cedar decking, boards, and log homes; veneer mills reliant on high-value hardwood species like yellow birch; and oriented strand board mills that use aspen. Finally, even if catastrophic species losses were avoided in Maine, the industry

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is still vulnerable to a massive die-off in other parts of the globe if other regions dump inexpensive wood and wood products on global markets.

The future of Maine's forest products industry

Changes in technology, global competition, and forest conditions due to climate change will create opportunities for the forest products industry as well as the need for current industry to adapt to these changes. The foundations of Maine´s forest industry include the land, harvest and distribution contractors, primary and secondary processors, and the employees and business owners that comprise the sector. Each step of the production process is subject to wide uncertainties under likely global climate change scenarios. As a result, the industry should be viewed as an integrated whole in assessing opportunities for adaptation to climate change. As in the case of a terrestrial ecosystem, if this industrial ecosystem or economic "cluster" loses key links due to the inability to adapt to rapid transitions, then the entire sector is endangered.

The Maine forest products sector is part of a global industry, and thus is influenced by multiple external factors in addition to climate: changing forest conditions, consumer demands (see box below), labor and environmental regulations, processing and distribution costs and technologies, and increased global competition (Trask *et al.* 2008).

A key attribute of the Maine forest is its ability to naturally regenerate without expensive planting. Global forest products competitors from areas such as Chile, Brazil, New Zealand, and parts of the southeastern US are largely plantation-based, and an increasing proportion of global harvests are coming from plantations (Sampson 2005). Plantations would represent a significant change for the Maine forest and create questions regarding biodiversity. One element of biomass sustainability is maintaining the biodiversity of the source forests.

It is unclear how climate change will influence workforce development issues, such as aging demographics within Maine's logging sector (Egan and Taggart 2004) and the increasing investment needed to remain competitive in harvesting and hauling timber. Fuel costs for harvesting and hauling are also climate-sensitive.

Finally, the foundation of Maine's forest industry is *the land*. Maine lies at the eastern edge of the 26-million-acre Northern Forest, and hosts the largest undeveloped forested block in the eastern US. The health of Maine's forest products economy—as well as the region's rural communities—depends on access to this forest. Such access is increasingly uncertain under changing ownership patterns and land-use trends (see box on next page).

Supply & Demand in the Forest Products Industry

Maine is 90% forested, and over 95% of that—roughly 17 million acres—is classified as productive timberland, both the highest percentage for any state in the nation (NEFA 2007).

Maine ranks first in timber harvests and forest products output in the northeastern US, and second in the nation in paper production (Innovative Natural Resource Solutions 2005). Moreover, harvests are stable and at or near long-term sustainable levels, while softwood and hardwood lumber production have increased 250% and 400%, respectively, since 1975 (Innovative Natural Resource Solutions 2005). Unfortunately, these efficiency gains have largely occurred through increased capitalization that has displaced labor as a factor of production, and resulted in job losses throughout the sector. Changing markets and technologies have led to closure of many small wood processing plants.

Nationally, wood consumption, imports, and harvests also increased during this time. However, beginning in the late 1980s, globalization, a strong dollar, and steep declines in federal timber harvests led to increased imports of lumber and panel products, as well as a loss of many export markets. Growth in the pulp and paper sector has slowed in recent years, and analysts expect little expansion in US pulp and paper manufacturing capacity for at least the next decade (Haynes 2003).

Global timber harvests, mostly for pulpwood, have increased by 60% since the early 1960s, and demand for forest products is growing as the world's population increases. Rapidly increasing living standards in densely populated developing countries such as China and India (Friedman 2005) will further intensify pressure on forests. As rural populations decline worldwide (United Nations 2008), forest product consumption becomes more reflective of the demands of urban dwellers (*e.g.*, less demand for single family homes and firewood).

Along with the increased demands for building and consumer products will be an increased need for energy. Today, most of the world still relies on wood for heating and cooking. Even in Maine, forests supply 20% of the state's electrical needs, and 25% of overall energy (NEFA 2007). Nine biomass-fueled electricity generating plants and three wood pellet mills are located in Maine, with additional mills being planned. Many forest industries rely on wood to generate much of the energy they need to support their manufacturing process. Firewood sales topped 400,000 cords in 1999 (latest available data), and are expected to increase as fuel oil costs rise (NEFA 2007).

Development Pressure on Maine Forests

The last few decades have seen a major shift from forest industry control of Maine timberlands to a host of largely financial interests. Financial investors now control approximately one-half of Maine's large timberland tracts, while industry control has fallen to just 15% (Hagan *et al.* 2005). Changing tax and investment laws, globalization, intense competition within the forest products sector, and increased demands for residential and resort development drove these ownership changes. As a result, management objectives of Maine's forestlands now include a broader range of goals.

In addition, development pressure is fragmenting Maine's forests into smaller parcels, especially near existing metropolitan centers (Brookings Institution 2006). Between 1980 and 2000, development altered over 850,000 acres of Maine forest—an area the size of Rhode Island. This loss was the result of just 65,000 new residential dwellings, making Maine's conversion rate of 10 acres per new housing unit the third highest behind Vermont and West Virginia (Brookings Institution 2006). These trends will likely continue based on analyses by the USDA Forest Service (Figure 21; Stein *et al.* 2005, White and Mazza 2008). Even in remote areas, forest land values have risen to prices above that which can be solely attributed to long-term forest management (LeVert *et al.* 2007). And one acre converted to residential development can compromise many more acres for future timber production, a phenomenon known as "shadow conversion."

Over time, these pressures have the potential to adversely affect the state's forest-based economy through (Alig *et al.* 2004): (1) increased parcelization of ownerships; (2) increased residential development and the fragmentation of forests; (3) heightened concerns and regulation over timber harvests and recreational use; (4) reductions in the land area available for timber harvests, recreation, and tourism; (5) decreased landowner investment in forest management; (6) increased taxes as municipal budgets and demands for services rise; and (7) increased traffic and congestion that may affect timber hauling costs. A related concern is the long-term energy costs of servicing sprawling suburban development across the landscape.

Development in Maine's Private Forests, 2000 and 2030

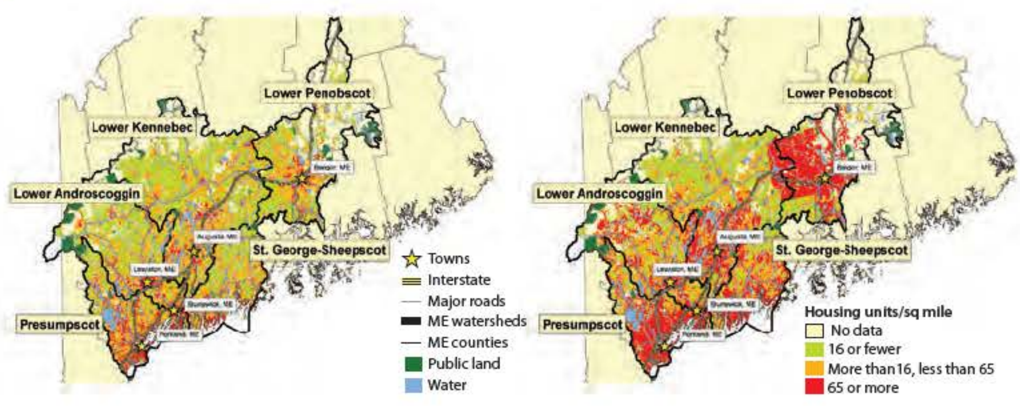

Figure 21 Current and projected housing unit density in southern Maine over the next two decades (White and Mazza 2008).

Opportunities & Adaptation

A significant factor affecting the industry will be the rate and magnitude of climate change, and how these changes influence the adoption of new technologies and resulting product mix. In general, rapid change is difficult to respond to given fixed technologies and input uncertainties that increase the inherent risks within the forest products sector.

New technologies have allowed the manufacture of a wider variety of products from the forest, expanding the usable portions of the tree. The introduction of pulp and paper to Maine over 100 years ago created a market for smaller trees not suitable for the sawmill industry. More recently, composite materials use small trees to manufacture large, more uniform materials to both compete with traditional lumber markets (beams, sheathing, packaging) and evolve into new markets not possible without technological advances (*e.g.*, long-span beams and narrow aspect shear walls). The interaction of forest characteristics and conversion technology ultimately dictate those products which are made and also help define the future forest condition. New products which are more flexible about the type and attributes of the wood required will be more adaptable to change.

As industry consolidation continues, the need to be globally competitive will drive the need for continued investments, such as the current $39 million investment at the Huber oriented strand board (OSB) mill in Easton (although such investments are predicated on long-term availability of wood). The recent $140 million conversion of the LP mill in New Limerick from

OSB to oriented strand lumber added 40 jobs to an older facility which was becoming increasingly uncompetitive.

Maine's paper industry is dominated by coated fine paper and specialty paper production, which have a major competitive advantage because of the quality of fiber from Maine's slow-growing tree species. As a result, manufacturing infrastructure has evolved over recent decades to focus on coated paper. Transitioning to specialty or technical grades of paper (or paper made from different trees) represents potential technical and economic challenges, and innovation will be key to future success in this area.

The development of products that can use biomass components of the forest that are not currently economically viable could create opportunities for forest management practices (*e.g.*, pre-commercial thinning), which could increase growth rate and may permit longer rotation ages. Hardwood species such as oaks and hard maples, which can be converted to high-value lumber for furniture markets, could increase in quantity and quality under appropriate silvicultural prescriptions. Alternatively, products and uses that are indiscriminate to wood quality may create preference for shorter-rotation, biomass-oriented management schemes for lower timber grades (*e.g.*, pulpwood and smaller).

One technology based on lower grade wood supply is the "biorefinery" model, which adds value by selling a wide range of consumer and industrial chemicals derived from wood. Like the oil refining business, it will be anchored with a relatively large volume commodity product, such as paper, which enables the economy of scale necessary to process large quantities of raw material. Also like the oil refinery model, smaller-volume, higher-value products will need to be diversified between refineries. Biorefineries cannot expect to receive high value for products that become over-produced. Where the biorefinery model differs from the existing pulp and paper industry is that instead of using the residual wood components as a boiler fuel, which is a low-value use, they are used for higher-end products. This is accomplished through separating the wood components and then using each for their own highest-value use. Structurally-strong cellulose is best for paper and construction materials, and lignin is the highest energy-containing component in wood. Hemicellulose is a relatively poor fuel for combustion, but is valuable as a food source for organisms that produce higher value chemical products, such as organic acids and higher alcohols.

Forest biomass has been used as a fuel for all of human history and is the most widely used fuel in the world. Unlike other renewable energy resources suitable for Maine, such as wind or tidal power, biomass can be stored over time. Wood has low density, is relatively dirty to burn (though low in net CO_2) and cannot be used in internal combustion engines, therefore it commands a low price as a fuel. Thus, to add value to wood as a fuel, it needs to be improved along these three metrics. Pellets are an improvement over biomass and firewood as they burn more cleanly and are easier to deliver through automated feed systems. If wood is fractionated, the lignin portion makes a more valuable fuel as it is more energy dense. Adding lignin to pellets improves their pelletizing properties and increases their energy density. Gasifying wood reduces the pollution associated with burning wood and makes it possible to run a combined-cycle gas turbine, making it more efficient for generating power than current steam-cycle applications. Ethanol from biomass adds considerable value to the fuel as it is a good quality transportation fuel. So-called second generation biofuels such as butanol or biomass-derived hydrocarbons deliver higher energy density than ethanol and are more compatible with the existing hydrocarbon fuel infrastructure. In some cases, some of the energy needed to upgrade wood to higher quality fuels can be derived from low-grade waste heat in a biorefinery. However, as with all energy supplies, it requires an expenditure of some energy to raise the quality and utility of other energy.

Market dynamics and policies will influence the success of products (*e.g.*, pyrolysis oils, levulinic acid, pellets) which use technologies distinct from pulping processes, and their competition with traditional forest product industries. This competition is already occurring in Sweden, where a 1991 carbon tax has resulted in significant increases in the use of wood biomass for energy.

Maine may have a significant opportunity in this transition due to the existence of smaller pulp and other forest products facilities, which are of an appropriate scale to be modified over time. The transition of such existing infrastructure in

Rob Lilieholm

conjunction with existing supply-chains, rather than construction of new "green-field" sites, will require adaptation.

Increased public awareness of climate change is likely to drive consumer interest in climate-friendly products. In this respect, forest products offer a number of advantages over product substitutes, being renewable, recyclable, and sustainable. Indeed, the inherent lower energy requirements of wood will make products from sustainably managed forests more attractive (Sathre and O'Connor 2008).

Here, Maine has been a national leader, with 37% of the state's productive forestlands under independent third-party environmental certification through standards set by the Sustainable Forestry Initiative, Forest Stewardship Council (FSC), and the American Tree Farm System. Maine's first-in-the-nation Master Logger program has certified over 100 loggers across the state in environmentally sensitive harvest practices. And the 2003 Maine Forest Certification Initiative set forth a goal of 10 million acres of certified forestland in the state. While Maine was an early leader, the amount of certified timber has rapidly increased worldwide. Over 250 million acres are FSC-certified, the equivalent of 7% of the world´s productive forests.

Rob Lilieholm

For continued success, marketing of Maine's forest products needs to increase, as certification processes will become more sophisticated and techniques such as Life Cycle Analysis and documentation of the carbon sequestration value of solid wood products and forest system will be necessary.

Alternative policies should include a firm commitment to shared prosperity for the region's rural communities through economic diversification strategies that take advantage of the region's social and natural assets.

Knowledge gaps

Knowledge gaps fall within four broad areas: (1) uncertainty regarding feedstock availability; (2) global changes within the forest products sector that affect product supplies and market competition; (3) effects of future regulations and policies on markets and competitiveness between sectors; and (4) the mix of products produced within the forest products sector.

Specific gaps within these areas include:

How will global climate change affect forest species composition, productivity, health, and mortality? Will climate change cause increased severe weather, which will induce code requirements for higher performance building materials? How will these changes in turn affect the composition and timing of raw material supplies to the industry?

Will changing climate alter the ability of Maine's forests to naturally regenerate? If artificial regeneration is required through planting, how would this affect biodiversity and forest-related stakeholder values, such as scenic quality and recreational suitability?

How will changing ownerships and land uses like residential development affect forest investment and access to timber? How will industry respond to these changes?

How will climate-induced changes in forest productivity here and abroad affect global competition within the forest products sector? What are likely differential effects on the industry and silvicultural investment?

How will changing consumer preferences for green products affect the forest products industry? What effect will carbon markets and sustainability issues have on long-term price and demand for forest products and forestland ownership, and can Maine position itself to use this as a competitive advantage?

How will the production of different forest products in response to a changing climate affect employment within Maine's manufacturing sector? How would such changes affect the configuration of the forest products cluster (*e.g.*, harvesting, transportation, milling, and business-to-business sales of chips and shavings)? Emerging evidence suggests that wood-based energy uses like pellet mills will be far less labor intensive than pulp and paper production.

Finally, how will rising energy costs affect the industry? Will higher costs stimulate new markets for wood-based fuels, provide opportunities for energy sales to the electrical power grid, or drive the co-location of compatible industries that can more fully utilize co-generated heat and electrical power? Or will higher energy costs undermine profitability within the sector? The implications are likely to be complex and unique to different players within the broader forest products sector.


Photo courtesy Maine Office of Tourism

Tourism & Recreation

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Tourism in Maine relies heavily on outdoor and recreational activities, most of which are defined by climate conditions. Climate change will likely lengthen the season for some recreational activities, while decreasing the number of days available for enjoying others.

While some tourism experiences (*e.g.*, snowmobiling) may be degraded by increasing temperatures, Maine tourism may still benefit overall if Maine's climate remains superior to the climate in competing regions.

Tourists who visit Maine to fish or view wildlife may be forced to seek recreation elsewhere if certain desirable species migrate north as a result of climate change.

Tourism is a major component of the Maine economy. In 2006, residents and out-of-state visitors made 10 million overnight trips and 32 million day trips to Maine destinations. These trips accounted for $6.7 billion in sales revenue across the state (Longwoods International 2007). The Maine State Planning Office estimates that the tourism industry supports 140,000 jobs and generates $3 billion per year in earnings.

Climate and tourism

Tourism in Maine relies heavily on outdoor and recreational activities, all of which depend on certain climate conditions. Relative to national averages, a high percentage of Maine's overnight visitors participate in activities such as canoeing, day cruising, swimming, bird watching, hiking, fishing, and experiencing the natural environment (Longwoods International 2007). Some of the perceived strengths of Maine's tourism industry include, but are not limited to, "excellent snow skiing/snowboarding," "great river rafting," "excellent mountain climbing," "great for mountain/off-road bicycling," "great for sailing," "good for viewing wildlife/birds," "not too crowded," and "good weather in the summer."

Some of the perceived weaknesses of Maine's tourism industry, most relevant to climate change, are revealed by low ratings for "good weather in the spring" and "excellent climate overall." Temperature warming trends could diminish or enhance these perceived strengths and weaknesses.

The future of tourism in Maine

Increasing temperatures may lengthen the season for some activities. By extending the peak tourism season, climate change could enhance Maine's perceived strengths related to mountain climbing, bicycling, and sailing, and lengthen the season for swimming, golf, and riding all-terrain vehicles (ATVs). Currently, tourism activity (as indicated by lodging sales) peaks in the summer, with July and August accounting for over 40% of total lodging sales in recent years (based on data from Maine Revenue Services). In comparison, May and October are now considered part of the "shoulder seasons" on either side of the peak summer tourism season. Under the climate change scenarios, the average temperatures in May and October are expected to increase by an average of 0.3-0.4°C (0.5-0.7°F) per decade. By the end of this century, the average temperatures in May and October could be only slightly lower than current average temperatures in June and September, respectively. This would benefit tourism businesses, but may deter visitors seeking to avoid crowds and high costs during what is now the shoulder season.

Warmer temperatures will reduce the number of days with suitable conditions for other pursuits. The effects of climate change on tourism and recreation are likely to differ across the state. Figure 22 shows average March temperatures in northern Maine and average April temperatures in coastal Maine. In northern Maine, the month of March has historically offered temperatures that are ideal for cold-weather outdoor activities

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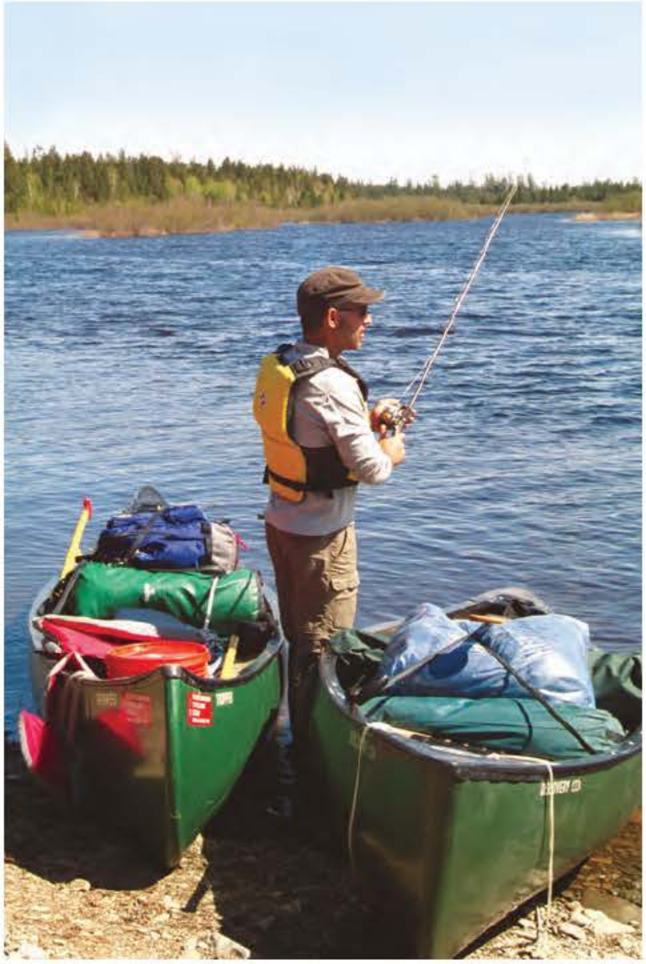
such as snowmobiling, skiing, ice fishing, and dog mushing (of course, December, January, and February also offer conditions suitable for these activities). Conditions must be below freezing in order to maintain a snow base for snowmobiling and safe ice conditions on lakes; in the absence of snow and cold, local economies and lifestyles are affected. For example, in 2006 a mild winter prompted Piscataquis County officials to ask for state and federal assistance to help winter tourism-dependent businesses (Associated Press 2006). Piscataquis County, which does not feature a network of roads that are maintained in the winter, relies heavily on snowmobiling and the network of trails throughout the county and state to provide access to local retail businesses, restaurants, and lodging.

Figure 22 shows that average March temperatures historically have been well below freezing in northern Maine, but by the second half of the 21st century, northern Maine may experience less than ideal conditions for cold weather activities in the month of March.

During the month of April (*Figure 22*), the southern coast of Maine has historically experienced average temperatures around 4°C (40°F). Although everyone has a different "comfort zone" for


Catherine Schmitt

Seasonal Temperatures in Northern and Coastal Maine, 1900-2100

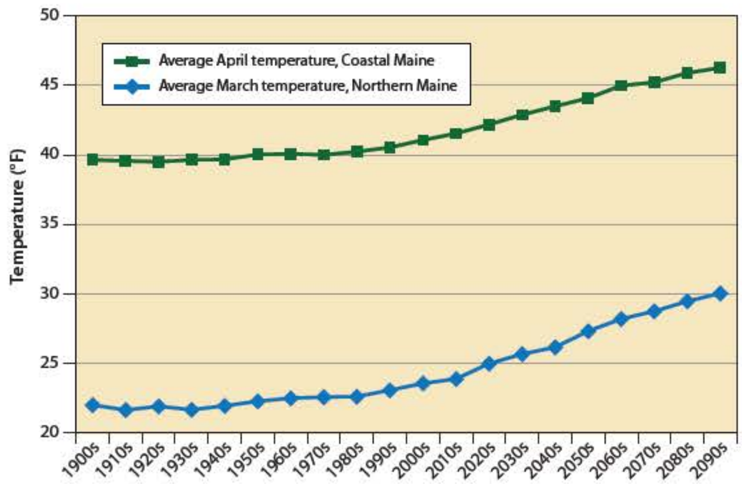


Figure 22 Average temperatures for March (Northern climate division) and April (Coastal division) for each year calculated across the 42 ensemble climatic states and averaged acros s the decades shown (see Appendix for details).

participating in outdoor activities, we are using 7°C (45°F) as the minimum (daily high) temperature required for activities such as golf, tennis, and bicycling (WeatherBill 2007). April climate conditions may be suitable in coastal Maine for many warm weather activities by the second half of the 21st century.

These examples illustrate how climate change may have positive and negative effects on tourism and recreational activities. Northern parts of the state may see a decline in the annual number of days with weather conditions suitable for cold-weather activities. This reduction in the season for activities such as skiing and snowmobiling may reduce the viability of some tourism-based businesses in northern Maine. On the other hand, coastal areas may experience an increase in the annual number of days with conditions favorable for warm-weather activities. This may provide additional opportunities for tourism-based businesses in southern and coastal areas.

Temperatures do not tell the entire story. Increasing temperatures may also bring increases in summer humidity and rain, rendering summer tourism less attractive in spite of the longer season in which to enjoy it. Likewise, increasing temperatures during the peak of the winter tourist season may damage Maine's winter tourism image with erratic temperatures and conditions (*e.g.*, mid-winter rain). This could yield less than ideal snow conditions for skiing or snowmobiling even in the middle of the winter when conditions should be at their best for these activities.

The cost of fuel will also affect transportation-based tourism, such as snowmobiling and boating. All of these potential changes could lead to unpredictable summer and winter tourism. Climate change, as it affects the landscape, may also affect tourist experiences in activities such as bird watching, wildlife viewing, and fishing. Cultural heritage tourism attractions and activities may be diminished by the potential loss of moose, trout, and brown ash trees from certain areas of the state. Tourists who visit Maine to fish or view wildlife may be forced to seek recreation elsewhere if certain desirable species migrate north.

Opportunities & Adaptation

Changes occurring outside of Maine influence tourism here. If warmer temperatures in southern areas increase the number of visitors to Maine during the summer months, the state may need additional infrastructure (*e.g.*, hotel rooms, roads, etc.) to accommodate tourists during what is already the peak season. Likewise, if the summer tourism season is extended by several weeks into both May and October, the industry will need workers able to commit to a longer period of employment. This may increase the current conflict with the US government over the limited number of work visas for young workers from foreign countries who seek seasonal employment in Maine's hospitality businesses. The state's tourism industry depends heavily on these seasonal workers. Additional vehicular traffic could also add to the air pollution that already clouds some of Maine's most scenic attractions.

Other influences may affect how readily a longer season can be converted into increased numbers of travelers and increased travel dollars during what is currently an off-peak travel time. These influences include the traditional timing when schools open and close, which affects family travel plans and the availability of student labor to staff seasonal businesses.

Tourists may be drawn to the one part of Maine that is likely to remain relatively unchanged. The narrow coastal strip of Downeast Maine from Penobscot Bay to Cobscook Bay is cooled dramatically by the upwelling cold waters in the eastern Gulf of Maine/Bay of Fundy. As described earlier in this report in "Maine's Climate Past," (page 10) this region remained cool and moist even thousands of years ago, when interior Maine was much warmer and drier, and there is every reason to suspect that the region will be cool and moist in the future (as the twice-a-day tides will continue to bring cold water to the coast). As heavily populated regions of the Northeast megalopolis (Washington, DC to Boston) become increasingly uncomfortable in future summers, the cool environment of coastal Maine could be even more valued than it is today.

Knowledge gaps

Will changing weather conditions affect the number of visitors to Maine?

Given that other regions will be affected by climate change as well, how will Maine's competitive advantage change relative to other places? An examination of climate change projections elsewhere and surveys of current tourists (and those who do not visit Maine) could help shed light onto these issues.

How will future visitors (and residents) respond to degraded natural resources, affected directly by changing weather conditions and indirectly from a potential increase in visitors?

Can we quantify the economic impact of climate change on tourism and recreation in Maine? This type of analysis would require a system to monitor tourism visitation, as well as climate and changes in ecosystems that attract Maine's visitors, such as bird and mammal populations (*e.g.*, moose). The temperature and relative humidity, as well as the number of rainy/snowy days, should also be monitored at a scale and scope that will facilitate analysis of visitor impacts across the state.

Photo courtesy Maine Office of Tourism

Transportation

Team leader Jonathan Rubin
Author Jonathan Rubin[1]
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Transportation accounts for 40% of Maine's greenhouse gas emissions. More than 95% of Maine's transportation energy comes from petroleum.

Reducing transportation-related petroleum demand and emissions will benefit Maine's economy, and requires increasing vehicle efficiency, switching to alternative fuels that have lower emissions per mile, and reducing local demand for transportation.

Reducing transportation emissions to mitigate climate change can have other benefits by improving air quality, alleviating traffic, and reducing oil dependency.

Transportation is key to the economic and social well-being of human society. We all have to move around. Yet transportation is responsible for many pressing problems related to climate change, including local and regional air quality, land-use change, quality of life, oil dependency, and greenhouse gas emissions.

Climate and transportation

There are two ways of thinking about transportation and climate change: how transportation systems affect the climate, and how climate change is likely to influence the various modes of our transportation system. These dual effects demand that we mitigate emissions as well as adapt our transportation system to the changing climate. Reducing emissions in response to climate change, in turn, can have other benefits by improving air quality, alleviating traffic, and reducing oil dependency (Kahn-Ribeiro *et al.* 2007).

Transportation-related greenhouse gas emissions consist largely of CO_2 from combustion, but they also include methane and nitrous oxide from combustion, and chlorofluorocarbons from the use of refrigerants for mobile source air-conditioning units. Nationally, 96% of transportation energy comes from petroleum (Davis and Diegel 2007); this amount is even higher in Maine, as currently we use very little biofuels, natural gas, or electricity in transportation. Transportation's total influence on global warming is likely underrated, as aircraft emit greenhouse gases directly into the upper troposphere and lower stratosphere (Penner *et al.* 1999). Transportation also has an indirect effect on climate change by affecting land development patterns (Rubin 2006, Ewing *et al.* 2008).

Transportation accounts for 28% of US greenhouse gas emissions (EIA 2007). In Maine, transportation accounts for 40% of the state's greenhouse gas emissions (MDEP 2008), reflecting the rural character of the state. Maine ranks 14th in the nation for the number of highway miles traveled (14,912 miles per year per capita) and 89% of Maine's work force commutes to work by passenger vehicle (Noblet *et al.* 2006).

Since greenhouse gas emissions are proportional to the amount of fuel purchased or (in the short term) the number of miles driven, the price of fuel can have a large influence on emissions. Figure 23a shows the nominal and inflation-adjusted average price of gasoline from 1950 to 2008. By historical standards, the price of gasoline has been low until quite recently, and prices were falling again in late 2008. Inexpensive fuel has led, in part, to the shift towards heavier and larger vehicles with lower fuel economy. Figure 23b shows a clear, upward trend in total vehicle miles traveled (VMT) on Maine's roads, with a 59% increase between 1985 and 2006. How much of the leveling off of VMT growth in 2007 is due to the rise in fuel prices is unclear. Other factors, such as low population growth with a general population shift towards southern and coastal parts of Maine, are also important.

The future transportation climate in Maine

Very few studies have examined state or regional vulnerabilities to climate change in the transportation sector. One notable exception is the Gulf Coast Study (US Department of Transportation 2008), which found that 27% of major roads, 9% of rail lines, and 72% of ports are potentially vulnerable to

1 Margaret Chase Smith Policy Center, University of Maine; 2 Maine Department of Environmental Protection; 3 Muskie School of Public Service, University of Southern Maine

Maine Gasoline Prices, 1985-2008

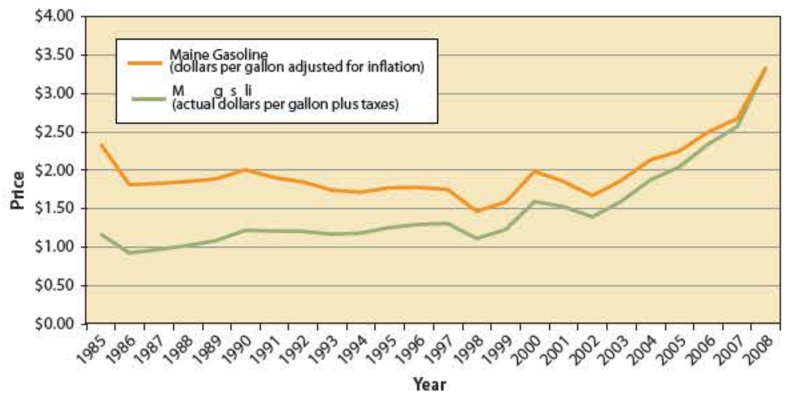


Figure 23a Actual and inflation-adjusted price of gasoline in Maine, 1985-2008 (EIA 2008b).

Maine Vehicle Miles Traveled, 1985-2008

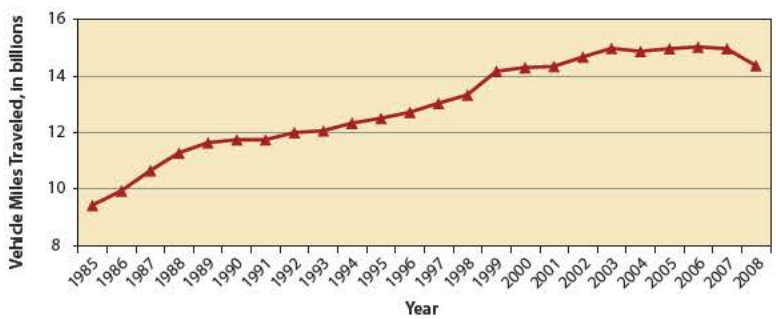


Figure 23b Annual vehicle miles traveled in Maine, 1985-2008 (Federal Highway Administration 2008).

flooding from sea-level rise in the central Gulf Coast region. Although a recent study has evaluated some types of economic impact of sea-level rise for coastal York County (Colgan and Merrill 2008), no comparable assessment has been conducted for Maine or New England. While these numbers cannot be used to assess Maine's potential vulnerability, they do give an indication of the potential magnitude of the problem. Through flooding and erosion, major storms may cause road washouts, rendering transportation infrastructure inoperable for long periods of time and requiring unplanned and high-cost replacement and repair (MDOT 2008).

Some climate changes will be beneficial for Maine's transportation system. As described in the section on tourism, the expected decrease in the length and severity of the winter season will likely reduce the cost of snow and ice control and provide safer travel conditions. Effects on transportation-oriented recreation including snowmobiling, ATV use, and boating can be expected, but the net impact on the economy is not clear. For example, expected decreases in snow cover will lessen the opportunities for recreational snowmobiling, but some of this loss may be offset by increases in the use of ATVs.

The larger issue of replacing infrastructure related to transportation and other sectors raises the important issue of engineering standards. Although national and state standards for construction of roads, bridges, culverts, and coastal structures are developed in a conservative manner, the implications of changing climate provide an excellent opportunity for reviewing those standards, especially as they are influenced by frequency and intensity of flooding, coastal storms, etc., in some localities. The Maine Department of Transportation has a major project underway to assess and develop strategies to replace existing culverts.

Opportunities & Adaptation

Actions to reduce petroleum energy use in transportation will directly aid Maine's economy. Maine DOT estimates that the strategic investments in highway and transit projects identified in their long-range transportation plan will reduce CO_2 emissions by 40 to 48 metric tons by 2030 (MDOT 2008). Reducing transportation-related petroleum demand and greenhouse gas emissions in Maine requires

- increasing the efficiency of vehicles (*e.g.*, miles per gallon);
- switching to alternative fuels that have lower emissions per mile; and
- reducing the demand for transportation.

Vehicle efficiency

In 2005, the Maine Department of Environmental Protection adopted two priority recommendations identified in Maine's Climate Action Plan: California emission standards for vehicles and California zero-emission vehicle mandates. Implementation of the tailpipe standards is subject to the legal challenge of EPA's denial of California's waiver for the California standards by Maine and other states. The zero-emission vehicle mandate has recently been changed by the California Air Resources Board to give vehicle manufacturers greater flexibility in meeting the production goals by increasing the number of plug-in hybrid and other advanced technology vehicles (CARB 2008).

These measures illustrate the complexity in designing and implementing policies to reduce transportation energy use. Unlike other sectors of the economy, transportation decisions involve multiple actors: private consumers and businesses that purchase and use vehicles; local, regional, and state entities who make decisions on land-use zoning and infrastructure development; and state and national representatives who rule on vehicle fuel efficiency and provide funds for transportation infrastructure and research.

Despite the setback in implementing California tailpipe standards, landmark federal legislation accomplishes similar goals. The Energy Independence and Security Act of 2007 increases the Corporate Automotive Fuel Efficiency (CAFE) standards of the US light-duty vehicle fleet from the 2007 (combined) level of about 25 miles per gallon (mpg) to the maximum feasible average to attain 35 mpg—a 40% increase. In addition, starting in 2011, the CAFE program will include SUVs that were previously exempt. These are national requirements that must be met on an average level. The actual fuel economy of new vehicles purchased in Maine depends, of course, on the decisions of Maine consumers and businesses. Public education on the value of purchasing more fuel-efficient cars and trucks can help ensure that Maine benefits from the greater availability of fuel-efficient vehicles that will be produced by automobile manufacturers. However, increases in vehicle and per capita miles traveled will more than offset the gains expected from higher CAFE standards (Ewing *et al.* 2008).

Alternative fuels

The Energy Independence and Security Act extends and increases the renewable fuel standard to require nine billion gallons of renewable transportation fuels in 2008, rising to 36 billion gallons by 2022. This equals approximately 16% of all the fuel used by cars, trucks, and SUVs, or 11% of fuel used by all vehicles including buses and heavy-duty trucks. As of 2016, all of the increase in renewable fuels must be met with advanced biofuels, defined as cellulosic ethanol and other biofuels derived from feedstocks other than corn starch (such as municipal waste or sugar); mandatory greenhouse gas emission reductions associated with these renewable fuels range from 20% to 60%. These reductions include methane and nitrous oxide, but do not include emissions from direct or indirect land-use change related to fuel sources or production.

The University of Maine's Forest Bioproducts Research Initiative is developing cellulosic biofuels using wood from Maine forests (FBRI 2008). The success and growth of this industry will depend, in part, on the technology-forcing mandates and standards that emerge in federal legislation. Success also depends on Maine vehicle owners' willingness to purchase these new fuels when they become available.

The Bangor Area Transit System uses biodiesel and the Island Explorer service on Mount Desert Island uses a completely propane-fueled fleet. The construction of a compressed natural gas fueling station in Portland will enable the METRO transit system, school buses, and US Postal Service fleet to switch to cleaner fuel (MDOT 2008).

Reducing demand

Compact development can be a crucial strategy in combating greenhouse gas emissions from automobiles. One of the best ways to get people to drive less is to build pedestrian-friendly places with a mix of uses, where people can walk, bike, or take transit from their homes to offices, schools, restaurants, and shopping (Ewing *et al.* 2008). Efforts by the Governor's Council on Maine Quality of Place and GrowSmart Maine to promote sustainable development and combat sprawl, if successful, will also help reduce demand for transportation. As jobs concentrate in the service center communities, the number of commuters will increase, requiring more park-and-ride facilities and commuter van pools. Urban transit systems may need to be expanded to more distant areas (MDOT 2008).

Knowledge gaps

Clearly, it would be prudent for Maine, alone or in conjunction with its New England and Atlantic Province neighbors, to pursue an inventory of the transportation sector's vulnerability to climate change. The Transportation Research Board of the National Academy of Sciences has made the following recommendations: inventory critical infrastructure such as coastal roads, railways, transit systems, and runways to assess their vulnerability to flooding due to severe storms and sea-level rise; factor anticipated climate change into investment and land-use planning decisions; integrate evacuation and emergency response to extreme weather events into transportation operations; and develop and implement monitoring technologies to give advance warning of infrastructure failures due to water levels, waves, and wind (TRB 2008). The State of Maine would be well-advised to undertake all of these recommended steps.

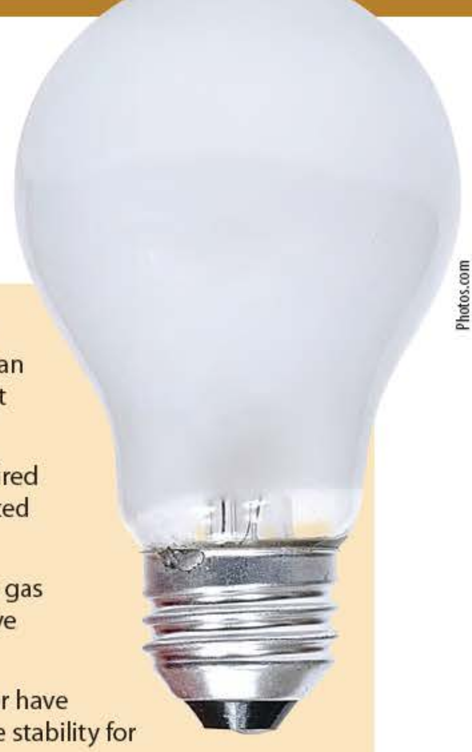
How can we promote sustainable development and transportation infrastructure without also changing the rural nature and quality of life of the state?

Public Transportation

One of the ways communities and individuals in Maine can use transportation to reduce their contribution to climate change is by increasingly choosing to use more public, and less private, transportation. According to the American Public Transportation Association, the use of public transportation reduces CO_2 emissions by more than 7.4 million tons per year across the nation (APTA 2008). Not only will this lower emissions by having fewer cars on the road, it will help individuals save from increasing fuel costs.

Overall, Maine has seen a significant rise in public transit use over the last ten years. According to Maine DOT, ridership not including air or rail was at approximately 3.8 million in 2004 compared to 2.4 million in 1999. The Downeaster rail service from Portland to Boston has seen significant increases since its inaugural year, starting at approximately 164,000 riders in 2002 to nearly half a million riders in 2008 (NNEPRA 2008). Increases in public transportation use in local areas can also be credited to the University of Maine's efforts to provide free bus service for students and staff.

Yet public transportation possibilities and capacity remain limited in Maine, because mass transit is only feasible in areas with certain population densitites and ridership rates.



Energy

Team leader Mick Peterson
Authors Anna Demeo,[1] Mick Peterson,[2] and Jonathan Rubin[3]
Reviewers John Ferland[4] and Michelle Portman[5]

Imported fossil fuels account for nearly three-quarters of all energy currently used in Maine. Maine's industrial and commercial sector uses more energy than the transportation and residential sector. Over 80% of Maine households heat with fuel oil, the largest percentage of any state in the United States.

Maine has significant potential for land-based and offshore wind and wood-fired electricity generation, and some of the best tidal energy resources in the United States.

Maine has shown regional and national leadership to reduce our greenhouse gas emissions. Maine could reduce energy expenditures by adopting cost effective measures used in other states, saving hundreds of millions of dollars.

Energy conservation, alternative home heating sources, wind, and tidal power have important implications for economic development, cost reductions, and price stability for customers, in addition to significant greenhouse gas emission reductions.

Energy can be viewed in terms of outputs, measured by emissions, and inputs, or sources of energy. Fossil fuels (coal, petroleum, and natural gas) account for nearly three-quarters of all energy used in Maine, and we import all petroleum and natural gas used for heating, transportation, and electricity generation. Biomass (mostly wood and wood waste) represents more than one-fifth of the electricity generation in Maine, a higher percentage than any other state (EIA 2008), a reflection of Maine's continuing economic activity in manufacturing and the forest products industry.

Maine's energy portfolio is unique among New England states and, in many ways, the entire country for two reasons. First, Maine differs from the rest of the New England region by having an industrial sector that uses more energy than the commercial and residential sectors. However, Maine's industrial sector uses a significant portion of renewable energy in the form of hydroelectricity and biomass (*Figure 24*).

The second most striking aspect of Maine's energy profile is that over 80% of households rely on oil for heat, the largest percentage in the US (EIA 2008). This, in addition to the fact that burning oil produces more greenhouse gases than other heating sources such as natural gas, is the reason why Portland has the highest per capita residential CO_2 emissions of the 100 largest metropolitan areas in the US (Brown *et al.* 2008). In northern parts of the state, per capita emissions are also higher because of the greater number of degree heating days (EIA 2008). Maine's large dependency on oil for heat is also a source of significant fiscal vulnerability due to the volatility of fuel oil prices.

Opportunities & Adaptation

Efforts to diversify residential, commercial, and industrial energy use away from oil and toward renewable resources can reduce emissions and vulnerability to a fluctuating global commodity market. Diversity of sources ensures that concerns which have occurred in the biofuels sector (such as environmental or financial costs), or which would be associated with a single high-risk approach, are avoided.

Alternative energy sources have important implications for economic development and cost reduction and price stability for customers. In fact, the economics of these technologies are such that they can provide an economic engine for the state economy by creating new companies and jobs, expanding business for existing firms, and lowering energy costs.

Energy efficiency & conservation

Increased energy efficiency has been identified as the single most effective way to enhance Maine's business climate and economic competitiveness (Colgan *et al.* 2008a). If Maine could reduce energy expenditures by adopting cost effective measures

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used in other states, businesses in the commercial (non-manufacturing) sector could save $230 million annually in energy costs, while businesses in the industrial (manufacturing) sector could save up to $129 million annually, for a total savings to the Maine economy of over $450 million per year at today's energy prices and utilization rates (Colgan *et al.* 2008a).

Alternative heating methods

Conservation through efficiency improvements and increased use of fuels other than oil are both key to reducing greenhouse gas emissions from residential heating. Over time, natural gas could play a greater role as regulation, incentives, and market forces increase pipeline infrastructure and allow more households the option of switching from oil to gas. Alternative hydrocarbon energy sources such as natural gas or propane result in lower emissions, but local supplies of these fuels could tighten in the future.

Near-term opportunities exist related to wood, combined with electric heat pumps. Heat pumps use electricity to transfer heat from cool to warm areas. The most common types move heat between the outside air and a house or building. Geothermal heat pumps transfer heat from the ground or a nearby water source. Because they move heat rather than generate heat, heat pumps can provide up to four times the amount of energy they consume (DOE 2008).

Heat pumps are very efficient under all conditions except for the coldest days when the ability to extract heat from the exterior air or near surface ground is limited, and here is where wood can play an important role in Maine's overall mix of heating sources. Wood can serve as an alternative, supplemental heat source on very cold days, when heat pump technologies are least efficient. Heat pumps are more effective on warmer days, when a wood heating system operating with a fully open damper (the most efficient mode) generates too much heat. Since only a small number of days during the year require large quantities of heat from a wood stove, particularly in the southern and coastal portions of the state, households in these areas would benefit from using complementary heat pump-wood products heating systems. The Governor's Task Force on Wood to Energy (2008) recently concluded that Maine has a sufficient amount of wood that can be sustainably harvested to supply the conversion of 45,000 homes (about 10% of Maine residences) from oil to wood heat over the next five to seven years. The implementation of heat pump-wood systems would greatly expand the use of wood heat for home heating beyond the current 10% projection.

Heat pumps rely on electricity. The savings in emissions gained by converting to heat pumps requires an increase between 2.5 and 4 gigawatts of electricity generating capacity, more than four times the output of the Vermont Yankee nuclear power plant. Increased use of traditional electric resistance heating would at least triple this need. Therefore, widespread implementation of heat pumps depends on the success of efforts to increase renewable energy generating capacity in the state.

Maine is fortunate to have a number of renewable resources that could be utilized such as water and wind power in addition to other conventional sources such as nuclear.

Maine's Energy Use

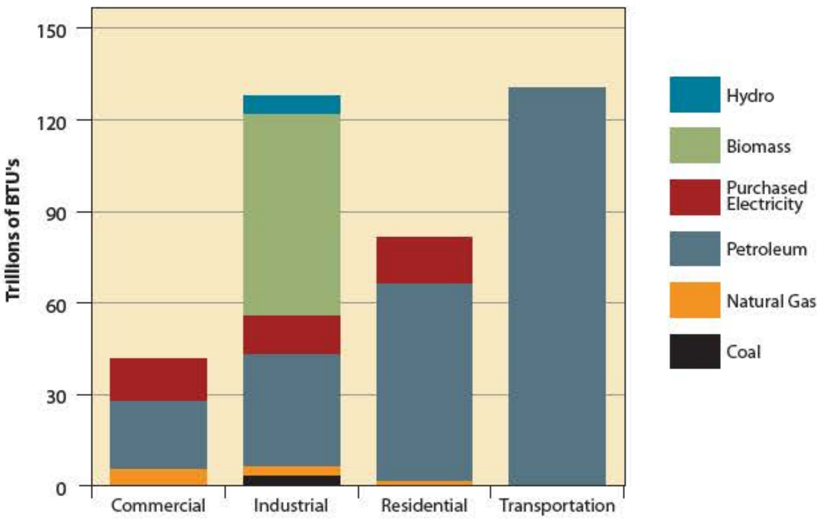

Figure 24 Energy use by sector based on 2005 data (Colgan *et al.* 2008).

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Power from the sea

The development of new technology is making possible the generation of emission-free electricity from Maine's tidal, river, and ocean currents. Tidal in-stream energy conversion devices hold promise of being one of the most sustainable methods of generating power, and several of North America's most robust tidal energy sites are located in Maine (Bedard and Hagerman 2006). Unlike dams, which impound tidal waters and operate similar to conventional hydroelectric plants, the new devices are placed in the free-flowing tidal stream to harness power from moving water, to capture part of its kinetic energy. Because the devices are deployed below the water surface, there are fewer visibility or navigation issues. Although power output is variable like many other renewable energy resources, tidal energy is predictable and therefore can be more easily integrated into the electricity grid for providing reliable power. Initial estimates put the total value of the resource in the range of 200-250 megawatts (Bedard and Hagerman 2006), although this number could prove conservative as research to develop and test the technology advances.

Because of the high degree of interest and the unique resources that exist in Maine, in-stream tidal energy is a promising near-term energy source which could have significant employment implications for the state, and provide the initial manufacturing and services infrastructure for the eventual creation of an ocean energy industry cluster.

Power from the wind

Maine has significant potential for developing wind energy both on land and offshore, and is listed as the best state for wind energy development on the East Coast and the 19th best in the nation (EIA 2008). Land-based wind production is already a reality in Maine, in the form of large-scale wind farms, as well as small independent wind turbine projects. Currently about half a dozen wind farm projects are at various stages of development, and only a fraction of the estimated eight gigawatts of potential wind power has been realized.

Terrestrial wind energy technology has seen a reduction in cost over the past two decades and is now competitive with fossil fuel-based sources (Wiser and Bolinger 2007). Energy costs average $0.03-$0.06/kilowatt-hour, depending on whether or not the Federal Production Tax Credit is applied (Maine Public Utilities Commission 2005).

With the Gulf of Maine's strong, steady, year-round winds, Maine is considered to be the best state for offshore wind on the East Coast (Gies 2008). Offshore wind projects are already making significant progress in Massachusetts, New Jersey, and Delaware. Proposals for projects in Maine waters differ in that they will be located much farther from shore and in deeper water, to capitalize on the steadier and 40% stronger winds that exist offshore. Wind turbines in these areas may be expected to produce up to twice as much energy as onshore ones (Berlinski and Connors 2006), although they also cost twice as much to build.

The extra cost of offshore wind farms is mostly due to construction and maintenance difficulties associated with working offshore in waters ranging from 60-90 meters deep, where 90% of Maine's offshore wind capacity lies (Musial 2005). Once constructed, however, offshore wind farms are expected to produce greater revenue per unit. The challenges facing offshore wind are the overwhelming costs of the required generating capacity, the realities of the capital markets, and the need to understand the value of the resource and the environmental costs (Pehnta 2008).

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Nuclear

With the bulk of uranium sources located outside of the US, nuclear power does not take us closer to energy independence, but it is a step towards lowering CO_2 emissions in the state. However, other environmental risks and security concerns and the associated costs need to be addressed in factoring this resource into Maine's overall energy plan. While such a plant is unlikely to be permitted within the state of Maine, nuclear will be a part of the overall generating mix with power coming from plants located in neighboring states and provinces.

The economics of conversion

A plan for gradually replacing fossil fuels with electricity generated from renewable sources is important for the health of Maine's economy, to promote energy independence, and to reduce Maine's greenhouse gas emissions. While cap-and-trade systems or a carbon tax may provide incentives for this conversion, the cost remains daunting.

Alternative energy sources in Maine are attractive because Maine's average electricity rate is 39% above the national average (although costs are lower than in many of our neighboring states). Significant portions of electricity costs are unrelated to generation, and include transmission, distribution, and "stranded" costs (OPA 2008). Stranded costs in Maine are associated with closed or divested generation capacity that remains as debts on the utility balance sheet which must be paid by the utility customers. These costs are insensitive to changes in the source of supply, and thus the addition of new sources of electricity will have minimal effect on consumers' electric bills. These non-supply related costs are a significant barrier to widespread substitution of electricity as a primary heat source.

Cost estimates must consider not only installation and construction costs, but also the capacity or efficiency of the generation technology. Nuclear plants have an average capacity factor of over 91%, depending on how often a plant stops and restarts (Blake 2007). Wind has a capacity factor of 25% to 40%, with recent gains due to improved turbine design and siting of turbines (Bird *et al.* 2005). It is reasonable to assume that this capacity factor applies to offshore wind, which is more consistent but carries greater logistical difficulties for maintenance and support. Tidal energy will likely have a similar or slightly higher capacity factor.

Another factor to consider when estimating costs (and carbon footprints) is the entire "life cycle" of a fuel source or power plant. Even offshore wind has related emissions and environmental concerns (Pehnta *et al.* 2008). Nuclear power is regularly touted as an energy source with zero carbon emissions. Although this is true at the point of generation, nuclear power plants do contribute CO_2 to the atmosphere via mining and processing of fuel, plant construction and operation, disposal of used fuel and waste products, and decommissioning activities.

The size of nuclear power's carbon footprint varies widely due to differences in plant type, location capacity, efficiency and expected lifetime (Sustainable Development Commission 2006). A reasonable estimate of total emissions from a 2.5 gigawatt nuclear plant is 1,354 million pounds of CO_2 (Sovacool 2008), which is far less than the 10,649 million pounds produced by the use of oil heat.

We have estimated that the conversion of 425,000 homes from oil to heat pumps would carry a one-time cost of $1.5 billion. This would require a major effort, but could potentially save $4,580 per year per house for a total savings of $1.94 billion per year. An additional cost would be incurred for wood pellet or other space heating for days when the temperature is too low for a heat pump to function efficiently.

Converting to heat pumps would require between $6.5 and $22 billion in capital investment in electricity generating capacity and upgrades to the transmission and distribution system. This capacity is unlikely to be met by any single source alone.

Capital costs for the construction and maintenance of terrestrial wind farms vary widely based on many factors including project size and location, but an average estimate of installed true capacity is $2,500-$4,000 per kilowatt-hour (kW; Maine Public Utilities Commission 2005).

Current estimates for deep-water offshore wind are $5,000 to $9,000/kW. The first offshore wind plants, such as the General Electric facility in Arklow, Ireland, cost an estimated $3,600/kW even though it was located in relatively shallow water where a single tower could be placed on the sea bottom. Current European shallow-water projects have cost between $1,800 and $4,000/kW of capacity with an actual output costing an average of $6,900/kW with the 39% average availability (European Wind Energy Association 2008).

The cost of constructing a new nuclear power plant is estimated at $5,000-$10,000/kW, with a total initial investment of $12 to $18 billion.

Tidal power has an estimated cost of $5,500/kW installed capacity.

Knowledge gaps

Realizing Maine's alternative energy sources like offshore wind will reduce the state's carbon emissions while creating a new industry in the state, but initial investment is necessary. How can the state prioritize energy spending in a global economy of wildly fluctuating energy costs?

What will it take in terms of cost, effort, and time to convert residential heating systems from oil to natural gas, wood, heat pumps, or some combination of these?

What can the state do in support of Maine's nacscent heat pump, tidal, and wind energy industries to ensure business competition and the existence of a trained workforce with reliable installation skills?

An Overview of Human Health Issues

Author **Marcella H. Sorg,** Margaret Chase Smith Policy Center, University of Maine

Anticipated climate changes threaten to decrease air quality, increase the spread of animal and microbial sources of disease, and increase danger from extreme weather events.

Maine's readiness for climate disruptions will require expansion of its public health monitoring systems, especially for infectious disease and lung health, improved connections with regional and federal health systems, and increased disaster response capability.

Humans can survive and even thrive in a wide range of climates. Although humans have built physical and technological buffers against some conditions, our health ultimately depends on the whole of our environmental surroundings, both natural and built—our modern human ecology. This is particularly evident in our vulnerability to factors mediated by climate, such as air and water quality, the spread of animal and microbial sources of disease, and the dangers posed by extreme weather events. Climate change has major implications for human health around the world, and this section provides a generalized overview of the issues most relevant to public health in Maine.

Climate and human health

Humans, like all other species, have adapted to a range of temperatures and available food sources, in systematic relationship to the plants, animals, and even the germs in our environment. This ecological view places humans in nature in an interacting community of organisms which feed us, and also which transmit disease. Just as our health is influenced by diseases in our environment, germs and viruses depend on humans for survival. All parts of a living community are affected by changes in temperature, rainfall, or the geographic ranges of organisms. Some of these effects are predictable, but the huge complexity of biological relationships creates uncertainty. The major areas of human health vulnerability include: (1) threats to clean air and fresh water; (2) a largely unpredictable influx of new germ-caused diseases; (3) increasing extreme weather events; and (4) mental health issues produced by disasters and human population death, injury, and displacement.

Temperature affects the geographic range of infectious diseases, but weather events affect the timing and intensity of outbreaks. The United Nation's World Health Organization (WHO) has warned that more storms, floods, droughts, and heat waves will be accompanied by an increase in climate-sensitive diseases, including malnutrition, diarrhea (an important cause of infant mortality), and malaria (McMichael *et al.* 2003). Two inches of rain in 24 hours is the threshold for the spread of infectious diseases, which have increased 14% in the US (Epstein 2008). Drought punctuated by heavy rains can be particularly destabilizing. Clusters of disease (borne by water, rodents, and mosquitoes) follow disasters, as public health infrastructure is damaged.

The future of public health in Maine

In Maine, climate change may have positive effects on health by increasing the agricultural growing season and reducing stress, injury, or deaths due to the cold. Nevertheless, most health effects are expected to be negative, and Maine will be influenced by climate effects on the health of populations around the world.

Warmer temperatures in the summer months and more frequent heat waves will increase heat-related illness. Heat stroke claimed tens of thousands of lives in Europe during 2003, and some US cities have also experienced increased deaths (Epstein 2005).

As temperatures increase, the geographic territories of disease-bearing insects will likely change, although the exact mechanisms are too complex for precise modeling. Because insects have metamorphic life cycles, temperature extremes and averages may affect life stages (*e.g.*, eggs, larva, and adult) differently. For example, Lyme disease is carried by the deer tick, *Ixodes scapularis,* which is associated with abundant deciduous forest, a moist climate, and the distribution of its most common animal host, the white-tailed deer (Rand *et al.* 2004). The deer tick also carries at least two other human diseases: human granulocytic anaplasmosis and babesiosis, and may carry Powassan encephalitis as well.

Lyme disease, identified in 1979 in Lyme, Connecticut, appeared in Maine at about the same time the first deer ticks were identified, the late 1980s (Rand *et al.* 2007). The incidence of Lyme disease, tracked by the Maine Center for Disease Control and Prevention (Robbins 2007), increased gradually at first, and has accelerated since the late 1990s, with a 37% increase in 2006 and 56% increase in 2007 (528 cases; *Figure 25*).

Since 1989, the Vector-Borne Disease Laboratory at Maine Medical Research Institute has researched ticks and their association with Lyme disease. Most cases are reported in southern and coastal Maine, particularly York and Cumberland counties, contiguous with the greatest frequency of identified deer ticks (*Figure 26*). The distribution of deer ticks has been moving north along the coast and up the major river valleys.

Cases of Lyme Disease in Maine, 1986-2007

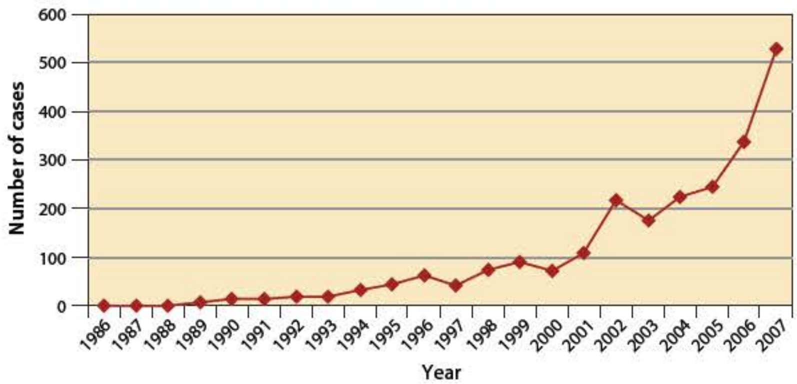

Figure 25 Number of cases of Lyme disease reported to the Maine Center for Disease Control, 1986-2007 (Robbins 2007).

Similarly, cases of Lyme disease have increased in Sagadahoc, Knox, and Lincoln counties, and in the lower Kennebec River valley. Model studies show that all of Maine will have conditions conducive to Lyme disease by 2080 (Epstein 2008).

Unstable weather is expected to alter the distribution of disease-causing mosquito species (Rosenzweig *et al.* 2001), and mosquito-borne diseases are increasing in Maine. Both West Nile virus and Eastern equine encephalitis have been identified in Maine animals, although no human cases have been reported.

Climate change extremes, including heavy precipitation in some areas and drought in others, can affect the supply of fresh water. More than 100 pathogens can cause illness through contact with water contaminated by sewage, including norovirus Norwalk, hepatitis A, and E. coli. Maine is at risk for water contamination with increased flood events, particularly in communities where sewer systems are not separate from stormwater systems, or in areas where surface water supplies are vulnerable to contamination. Outbreaks of water-borne disease such as giardiasis and cryptosporidiosis are expected to increase due to local precipitation-caused flooding (Relman *et al.* 2008). Giardiasis, sometimes called "beaver fever," is an intestinal parasite that lives in humans and other mammals and can contaminate drinking water. The number of giardiasis cases in Maine has fluctuated from 238 in 2000 to 197 in 2007 (Robbins 2007). Cryptosporidiosis, caused by an intestinal parasite, is frequently found in contaminated water such as swimming pools (it is resistant to many chlorine disinfectants), and is often linked to contact with farm animals. Reports of cryptosporidiosis cases remained stable at 20 reports in both 2000 and 2001, rising to 30 in 2005, 52 in 2006, and 56 in 2007 (Robbins 2007).

With rising ocean levels, coastal groundwater is at risk from increased salinity as seawater invades formerly freshwater aquifers. Warmer temperatures and increased rain and snowfall may increase the length and intensity of toxic algal blooms or "red tides" in coastal waters (Edwards *et al.* 2006; see also the Gulf of Maine section of this report).

Scientists expect air quality to diminish (Patz *et al.* 2000, McMichael *et al.* 2003, Weiland *et al.* 2004, Confalonieri *et al.* 2007). Increasing ozone and CO_2 contribute to smog, which causes more hospitalizations and deaths from asthma and chronic obstructive pulmonary disease (COPD; ALA 2007, Bell *et al.* 2007). In contrast to reductions in atmospheric concentrations of sulfate and toxic metals (page 14), deposition of nitrate, an acid rain-forming compound and an important forest nutrient, has not declined and remains an environmental concern. Nitrate, along with sunlight and airborne hydrocarbons, is important in the formation of ground-level ozone (or tropospheric ozone). The relatively constant levels of nitrate, sunlight, and natural hydrocarbons in the air assures a continuing presence of unhealthy ozone episodes. This is not to be confused with stratospheric or "good" ozone, which at high elevations (six to 30 miles) in the atmosphere protects life from the sun's ultraviolet light.

Distribution of Deer Ticks, 1989 – 2007

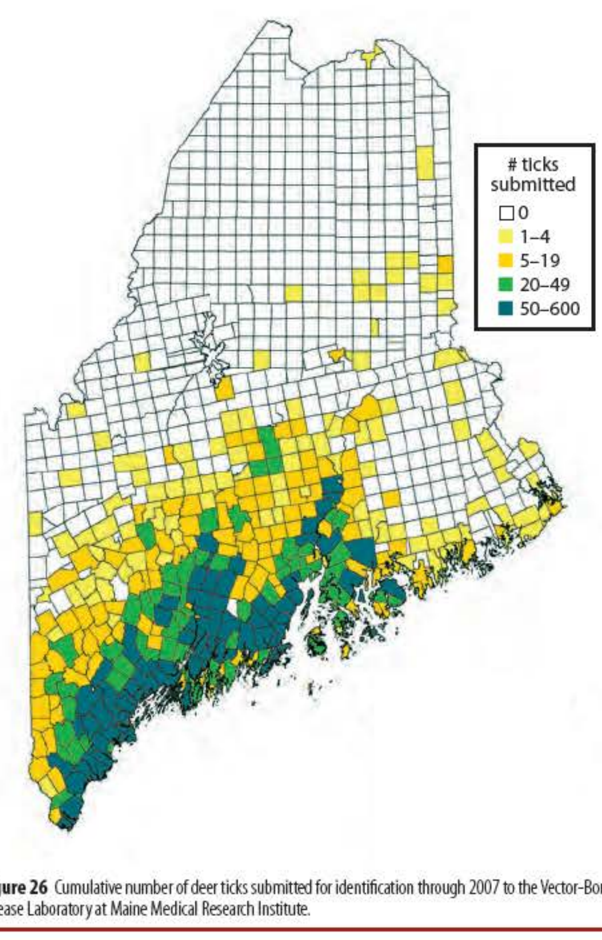

Figure 26 Cumulative number of deer ticks submitted for identification through 2007 to the Vector-Borne Disease Laboratory at Maine Medical Research Institute.

Emissions of synthetic chemicals from human activity (*e.g.*, chlorofluorocarbons) have depleted this ozone layer, leading to increased risks to human health.

Rising amounts of particulate matter, which can originate in areas outside Maine or locally from heating fuels and other combustion processes, also impair lung health. As heating oil becomes more expensive and Mainers are encouraged to burn wood, the potential exists for air quality degradation from wood smoke, even with newer stove types. Recent research comparing residential heating systems has found that, while the new pellet stoves produce about 10 times less particulate matter than conventional wood stoves, they still produce about 50 times more particulates than conventional oil furnaces, and more of some toxic substances (polycyclic organic compounds and naphthalene) than either conventional wood stoves or conventional oil furnaces (Dixon 2008). Thus, decisions about heating are linked to public health, especially the health of children and elders, and should be considered as part of the cost-benefit analysis in setting priorities (Byun 2008).

Pollen is one form of airborne particulate matter that can cause allergic responses, potentially compounding problems from air pollution, especially for those with asthma and/or COPD. Plants that produce allergenic pollens such as ragweed may be more numerous with higher levels of carbon dioxide, and produce greater quanities of pollen, or pollen that is more allergenic (Epstein 2005).

Finally, with the anticipated increase in severe weather events, along with the rising sea levels, the probability that people will be displaced from their homes will also increase. Mental health issues that accompany such family disasters are also expected to increase.

Opportunities & Adaptation

Public health successes in the 20th century, mostly focused on better sanitation and immunization, made great strides in reducing deaths due to infectious childhood diseases. Newer challenges have come from chronic diseases and diseases of addiction, and the behavioral changes needed to combat them. Now we must be prepared for an expanded variety of problems, some of which are difficult or impossible to predict (Frumkin *et al.* 2008).

Maine's statewide public health system is still relatively new, and will need to grow quickly and remain nimble as it faces the incoming threats that will be created with the changing climate. A robust public health system is one that can respond quickly to a range of potential problems, including issues with water supplies, air pollution, and a changing and largely new assortment of infectious diseases that need to be monitored and addressed (Epstein 2002).

Our ability to adapt to climate changes that affect health depends on having the knowledge to define and address new and emerging problems. It also depends on the speed with which we can respond to threats. Movement away from homeostatic systems of weather and climate, for which we have developed solutions to known problems, will present strong challenges to public health infrastructure. Maine's readiness for climate disruptions will depend in large part on investment in the expansion of the state's public health monitoring systems, especially with respect to infectious disease and lung health, interoperability with regional and federal health systems, and investment in disaster response capability (Frumkin *et al.* 2008).

Disaster and public health threat preparedness presents challenges in both policymaking and implementation. Some decisions about climate-related interventions for health will have to be made in the absence of secure data, and our public health infrastructure will need to incorporate expertise and resources for managing uncertainty (Glass 2008). The climate influences on health involve traditional public health topics of disease morbidity, mortality, and epidemics, but they also involve interactions among large-scale ecological processes and socioeconomic systems, and so public health planning will increasingly play an explicit role in policy decisions influencing the environment and the economy.

Knowledge gaps

Can we evaluate the public health risks posed by storms, flooding, and sea-level rise to water quality, and prioritize investment in upgrading wastewater treatment plants, combined sewer overflows, and private subsurface wastewater disposal systems?

More research is needed on emerging disease ecologies, particularly for vector-borne diseases as they invade temperate climates. Species-specific models will be required to differentiate complex relationships between vectors, hosts, and within an environment of changing population density, land-use patterns, and biodiversity issues.

Little is known about the specific pollutants carried in air and their effects on human health. Such pollutants change with new industrial and agricultural use and atmospheric release of chemicals, and potentially react with other substances in the air or water. What are the acute and chronic effects of these chemicals?

How can we create residential heating methods for Maine that reduce dependence on fossil fuels, but do not further pollute air and cause respiratory health problems?

Health policy research is needed to refine understanding of the complex public health needs and the roles of the public health system in natural disasters, including benefit/cost assessments that consider the diverse health consequences that occur: trauma, infection, nutritional deprivation, psychological damage, population displacement, economic loss.

Research is needed to develop methods of death investigation that better serve public health and safety surveillance and outcome evaluation. Expanded skills and protocols are needed to consider and document environmental causes of death.

An Overview of Economic Issues

Author **Charles Colgan,** University of Southern Maine

Climate change will affect agricultural lands, forests, and aquatic ecosystems, resources key to Maine's traditional economic foundation. Losses may be offset by new opportunities such as those presented by longer summers or new species.

Climate change could indirectly raise the costs of doing business in Maine. Warmer temperatures and sea-level rise will increase risks of flooding and coastal property damages, which will be incorporated into insurance rates and availability even before lasting damage occurs. Policy responses to climate change, such as cap and trade emission rules or carbon taxes, will alter costs in unknown ways, some of which may be to Maine's advantage and some of which may not.

Economic opportunities include the growing alternative energy industry, inventing new technologies for energy- and carbon-efficient products, and developing the expertise to help individuals and businesses adapt across all sectors of the economy.

Climate change offers the opportunity to build the local economy and healthier living through locally grown foods, community supported agriculture and fisheries, and reduced exposure to harmful chemicals.

In response to climate change, certain economic activities will be reduced or even eliminated. Costs will increase for some sectors and decrease for others. The potential growth of new economic activity could offset some or all of the negative effects of a destabilized climate.

Absent an abrupt or clearly dramatic climate change or sea-level rise scenario, the net effect of climate change, including the effects of mitigating actions, could be significantly negative or maybe slightly positive. The ultimate answer depends on the interaction of four different factors: changes in outputs, changes in costs, changed opportunities, and changed perceptions of time and risk.

Other sections of this report have described how climate change threatens the natural resources on which the Maine economy has depended. These include lobsters and other commercial fish species, the forests on which the forest products industry depends, four-season recreation, and sport fisheries.

At the same time, warmer temperatures may extend seasons for tourism activities such as cruise ships and boating. Longer growing seasons will permit farmers to expand the range of crops and animals in Maine agriculture. The forest products industry, which has been adapting to a changing softwood/hardwood mix since the spruce budworm outbreak of the 1970s, will continue and accelerate this adaptation. It is highly likely that Maine will continue to be characterized by forest products, fishing, and agriculture well into the future, but all of these industries will likely look somewhat different than they do today.

The impacts of climate change on the costs of doing business in Maine are less visible than changes in natural resources, yet changes in costs are likely to be as or more significant. Unlike the changes in the natural resource industries, some of which will occur in Maine independent of events elsewhere, the key to determining the extent of the cost effects will be how change in Maine takes place relative to changes elsewhere. Since climate change is literally a global problem, it will be affecting costs everywhere. The key question is: Will Maine be disproportionately negatively affected?

For example, as described in the section on freshwater ecosystems, water may become more scarce and costly in parts of Maine. The perception that Maine is "water-rich" will likely change as precipitation patterns become more variable and unpredictable. Extended periods of drought could drive up water prices, or require more expensive investments in infrastructure to maintain water quality and quantity. At the other extreme, periods of high precipitation will require greater investments in infrastructure to manage flooding events. Recent high-volume rain storms have already shown an alarming deficiency in the size of culverts needed to protect roads, and Maine is facing significant issues and rising costs in managing stormwater with existing water systems.

Other changes may be subtle but very real. A number of studies have pointed to the vulnerability of significant portions of Maine's coast to the increasing frequency and intensity of coastal storm damages resulting from sea-level rise associated with climate change. This is true in the beach communities of York County, but also in Portland, where the Commercial Street area is the site of regular flooding from storms (Slovinsky and Dickinson 2006).

Following the disasters of hurricanes Andrew (1992) and Katrina (2005), the private property insurance industry has been re-evaluating rates for property insurance in coastal areas. Private property insurance is almost unattainable in Florida


J. Kelley

and has become a major issue in places like Cape Cod (Mohl 2007). Federal flood insurance fills part of the need but does not cover damage from wind, as many homeowners along the Gulf of Mexico have discovered. The "insurance crisis" that is now afflicting many other coastal areas has not yet hit Maine, but it will probably only take one or two more repeats of 2007's Patriot's Day Storm to bring the issue to the fore.

Another set of changing costs will emerge from the responses designed to mitigate climate change. The two most significant economic strategies proposed for mitigation are cap-and-trade systems and carbon taxes. Maine is already participating in a cap-and-trade system through the Regional Greenhouse Gas Initiative. This approach will progressively ratchet down emissions, with those electric utilities able to do so most efficiently gaining an economic advantage, although the effects on different states are still unclear. Federal cap-and-trade systems may be created within the next two years. Their effects are even more uncertain, particularly how a national system would interact with a regional one.

A carbon tax, which many economists believe is the most effective strategy for mitigating greenhouse gas emissions (GAO 2008), is more uncertain as a policy measure. Maine's heavy dependence on fossil fuels would make the state vulnerable to disproportionate increases in costs, at least in the short run. However, in the long run, the state's response to a carbon tax could offset these cost disadvantages.

Opportunities & Adaptation

The need to mitigate and adapt to climate change also presents Maine with economic opportunities. These include ideas covered in more detail in many other parts of this report, including developing markets for Maine forests to be used for carbon sequestration and bioproducts. Most notable has been the significant investment already underway and planned in alternative energy generation, particularly wind power. If fully realized, the development of wind power generation could be a major industry in Maine for the next decade.

Other opportunities exist in developing and marketing the expertise to deal with climate change. Maine already has significant economic activity in its energy and environment clusters, including a significant environmental engineering industry. In addition, the worldwide demand for environmentally and energy efficient products is likely to grow significantly in response to climate change issues, creating significant opportunities for Maine firms that can tap these markets (Colgan *et al.* 2008b).

Knowledge gaps

One of the most significant economic questions emerging from the issue of climate change is how to respond to climate change when the most significant effects may be decades away, but the costs of mitigation and adaptation must be borne today, when resources to meet critical social, economic, and environmental needs are already short? Economists are criticized for believing that costs to be incurred in the far distant future are worth less than costs to be paid now, implying that the future consequences of climate change should be disregarded. Positive net economic benefits could result if the right choices on mitigation and adaptation are made, even while society continues to debate whether to make those choices, given the many uncertainties in the exact extent and timing of climate change (Nordhaus 2008).

Maine people are challenged to reduce the causes of climate change by reducing greenhouse gas emissions, while simultaneously adapting to a changing climate that is already reflecting our history of escalating greenhouse gas emissions from the past century or longer.

V Conclusion: Maine's Leadership on Climate Issues

Historically, Maine has shown regional and national leadership in addressing environmental issues, and we continue to do so in the context of climate change associated with greenhouse gas emissions (see box). Maine conducted its first emissions inventory in 1995 (*Figure 27*), and Maine's Climate Action Plan is a pioneering initiative focused on reducing greenhouse gas emissions to limit the degree of climate disruption. However, evidence from ecosystem research and the climate record shows that Maine is already experiencing a changing climate, consistent with global warming predictions, perhaps at rates not experienced in modern times. We also know that given the amount of CO_2 already in the atmosphere, some degree of continued climate change is expected in the coming centuries.

Consequently, Maine needs to expand climate planning beyond mitigation to encompass adaptation to the changes that are inevitable, and to capture the economic and management opportunities presented by our changing chemical and physical climate.

Natural climate change and accompanying changes in ecosystems have defined Maine's landscape through geologic time. One major difference today is that more than 1.3 million people in Maine depend on the ecosystem services and natural resource-based economy that has been defined by the climate of the 20th century. The current challenge for Maine is to minimize the disruption to society and Maine's economy during a period of rapidly changing climate. A successful strategy for addressing both climate change and related energy concerns will identify and pursue new opportunities during this period of transition. The purpose of this initial assessment was to begin a dialogue that brings together a broad range of expertise to transform existing knowledge into meaningful and productive change.

A Timeline of Maine's Climate Actions (from Brooks 2008)

1995 First statewide greenhouse gas emissions inventory.

2000 State Planning Office drafts a Climate Action Plan.

2001 Governor King joins other Northeastern US governors and Eastern Canadian premiers in agreeing to regional greenhouse gas reduction goals.

2003 The Maine Legislature enacts the first state law to address climate change. Public Law 2003, Chapter 237, An Act to Provide Leadership in Addressing the Threat of Climate Change (38 MRSA §574-579), required the Department of Environmental Protection to develop and submit a Climate Action Plan for Maine with the goal of reducing emissions to 10% below 1990 levels by 2020 and, in the long term, "reduction sufficient to eliminate any dangerous threat to the climate. To accomplish this goal, reduction to 75% to 80% below 2003 levels may be required."

2004 Climate Change Action Plan is finalized.

2007 Maine becomes a charter member of The Climate Registry.

2007 Maine and other states adopt legislation to implement the Regional Greenhouse Gas Initiative.

2008 Governor Baldacci asks the University of Maine to draft an initial assessment of climate-related changes in Maine ecosystems.

2008 Maine takes part in the nation's first regional greenhouse gas emissions auction.

Maine Greenhouse Gas Emissions, 1990

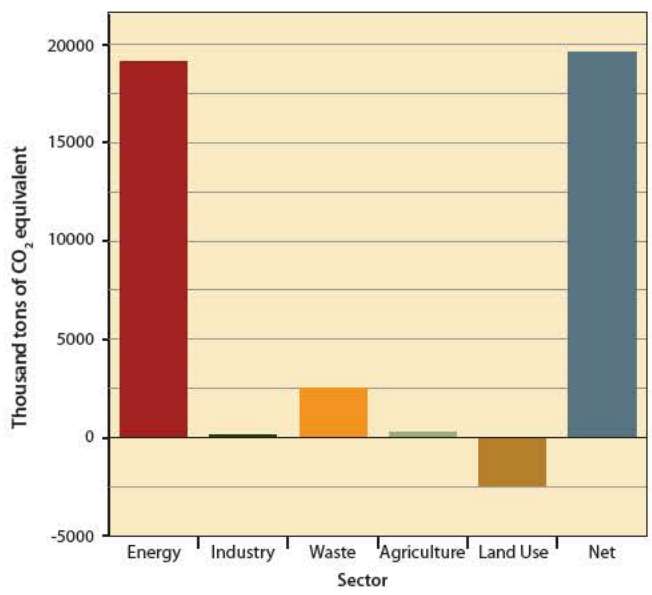

Figure 27 Maine's initial (and thusfar only) greenhouse gas emissions inventory conducted in 1995 using 1990 data (Simmons and Bates 1995). Total emissions from fossil fuel energy combustion are captured in the "Total Energy" column. Additional emissions are from non-combustion sources such as methane produced from waste and agricultural operations. Forest carbon storage increases are estimated to offset about 12% of total emissions.

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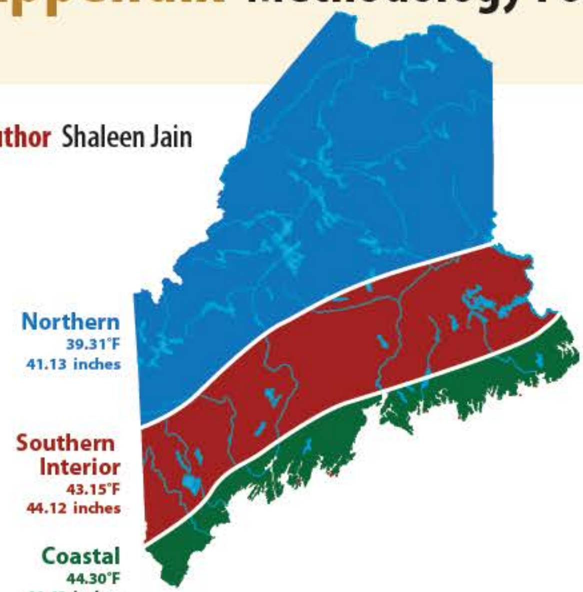
Appendix Methodology For Climate Change Projections

Author Shaleen Jain



Historical data

Changes in Maine's climate were analyzed based on temperature and precipitation records from NOAA's National Cl imatic Data Center. Linear trends for the 1895-2007 period were computed based on area-averaged monthly data for the three climate divisions (Northern, Southern Interior, and Coastal; above). These climate divisions span 54%, 31%, and 15% of the state's total area, respectively.

Although climate division data provide only a broad view of the climatic variation within the state, this dataset is considered a benchmark for monitoring and assessing long-term changes. Weather stations representative of the general climatic characteristic of a division are used in computations of the divisional averages. Furthermore, care is taken to adjust the records for reporting errors, and eliminate systematic biases and errors stemming from the time of observation, station relocation, and instrument change. As with most other climatic records, the quality and density of weather station data were somewhat sparse during the first half of the 20th century; as a result, for the pre-1931 period, simple averaging of all available data in the state was used to determine the divisional estimates (Guttman and Quayle 1996).

Climate model simulations

As part of the World Climate Research Program's Coupled Model Intercomparison Project, a coordinated effort led to the latest compilation of 42 simulations (from 18 different Coupled Atmospheric Ocean General Circulation Models, some of which are run multiple times) of the Earth's past, present, and future climate (see Table A1 for details; also Chandler 2008).

Greenhouse gas concentrations up to the year 2000 are observed values; thereafter, the concentrations are based upon the Special Report on Emission Scenario A1B (Meehl *et al.* 2007; see below). This scenario results in a CO_2 concentration of about 700 parts per million by the end of the 21st century (current concentration is 387 parts per million). The spatial resolution of the models is approximately 2° latitude by 2.5° longitude, which smooths topography and uses area-averaged representations of land and atmospheric processes.

Model Name (Country of Origin)	# of Runs	Run Duration Year start	end
CCSM3, (USA)	6	1870	2099
CGGM 3.1, T47 (Canada)	1	1850	2100
CNRM-CM3 (France)	1	1860	2209
ECHAM5/MPI (Germany)	3	1860	2200
ECHO-G (Germany/Korea)	3	1880	2099
FGOALS-g1.0 (China)	1	1850	2199
GFDL-CM2.0 (USA)	1	1861	2200
GFDL-CM2.1 (USA)	1	1861	2300
GISS-AOM (USA)	2	1850	2100
GISS-EH (USA)	3	1880	2099
GISS-ER (USA)	2	1880	2200
INM-CM3.0 (Russia)	3	1871	2200
IPSL-CM4 (France)	1	1860	2100
MIROC3.2-hires (Japan)	1	1900	2100
MIROC3.2-medres (Japan)	3	1850	2100
MRI-CGCM2.3.2 (Japan)	5	1901	2100
PCM (USA)	4	1890	2099
UKMO-HadCM3 (UK)	1	1860	2199
Total:	**42**		

Table A1 Individual Model Information. Organized table for the 42 model simulations used. Model names, country of origin, number of runs for each model, and year of the beginning and end of the simulations are shown. In the case where models having multiple runs run different lengths of time, the period common to all simulations is shown.

Emissions Scenario for the 21st century (A1B)

One important assumption used in the Coupled Model Intercomparison Project models involves the concentrations of CO_2 for each year in the 21st century. The different projections for greenhouse gas emissions are shown in Figure A1; Scenario A1B (green) is used for all models in this assessment. Each scenario is based on different projections of demographic development, socioeconomic evolution, and future technologies. None of the scenarios are asserted to be the best, because the variables involved are highly uncertain. All scenarios are equally likely, according to the IPCC. Scenario A1B is utilized herein because it is considered a medium projection (Meehl *et al.* 2007).

Scenario A1B assumes a future world of rapid economic growth. The world gross domestic product is assumed to grow to approximately $56 trillion (based on 1990 US dollars) in 2020, $181 trillion by mid-century, and $529 trillion by 2100. One major theme includes the declining wealth gap between the richest nations and those still developing. The ratio of the per capita income in the developed and transitioning countries to those in development is 6.4 in 2020, 2.8 in 2050, and 1.6 by the end of the 21st century.

World population is projected to increase at slower rates, until a peak of 8.7 billion around 2050. Energy consumption is expected to triple between 2020 and 2100, from 711 x 10^{18} joules (J) in 2020, to 1347 x 10^{18} J in 2050, and 2226 x 10^{18} J in 2100. Another major theme of this scenario involves the quick development of non-fossil fuel related energy sources. A balance of energy sources is assumed. The fraction of energy derived from zero carbon sources grows from 16% in 2020 to 36% by mid-century to 65% by 2100.

21st Century Global Emission Scenarios

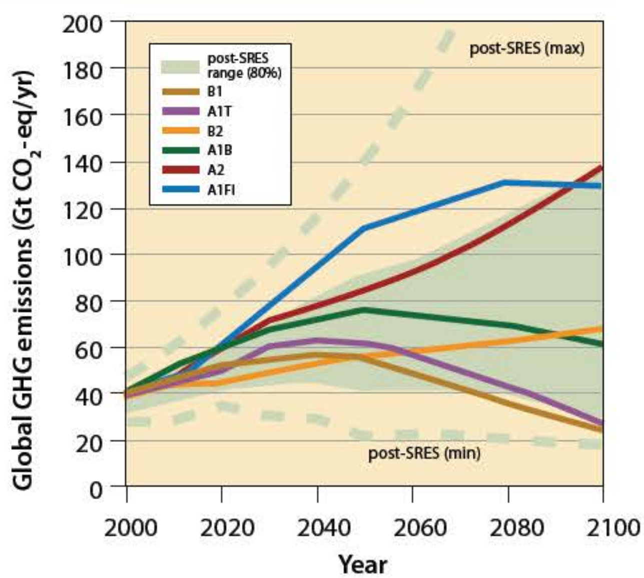


Figure A1 Projected global greenhouse gas emission scenarios, 2001 to 2100 (IPCC 2007a). The effects of anthropogenic forcing are evident in the models. The 5th and 95th percentile range of models using only natural forcing (solar and volcanic) is in blue, and the same ranges for models that also include greenhouse gas forcing in pink.

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