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 for roads, bridges, culverts, and coastal structures, 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 (*Figure 6*). 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 cult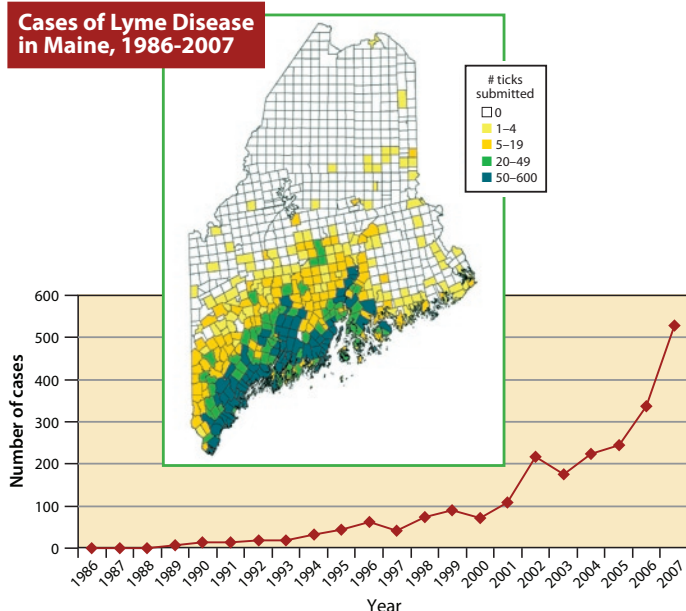urally invested in specific areas of Maine, and many of their values, meanings, and identities are closely linked with the natural landscape and physical interactions with that landscape. Tribal members tend to have close affinity with natural ecosystems, and the projected changes in biodiversity are likely to present adaptive challenges to the communities involved. Potential ecosystem responses to climate change may

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.

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.

Cases of Lyme Disease in Maine, 1986-2007

ticks submitted
☐ 0
1–4
5–19
20–49
50–600

Figure 6 Graph—Number of cases of Lyme disease reported to the Maine Center for Disease Control, 1986-2007 (Robbins 2007). Map—Cumulative number of deer ticks submitted for identification 1989–2007 to the Vector-Borne Disease Laboratory at Maine Medical Research Institute.
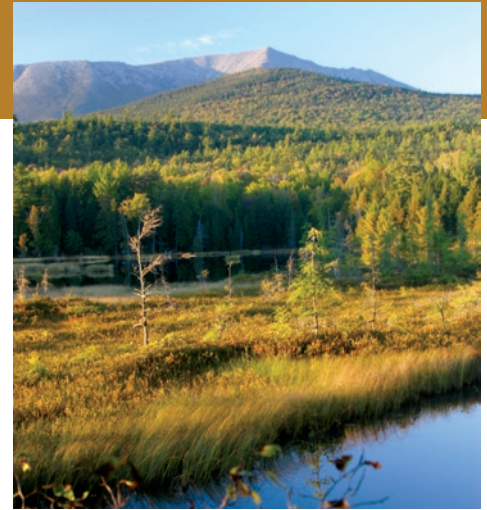
Maine's Climate Future
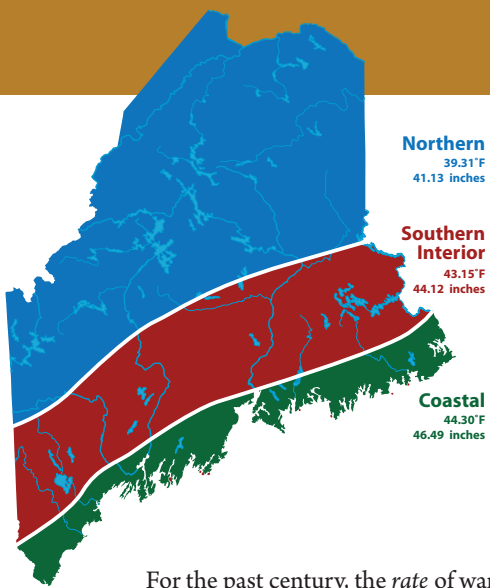
An Initial Assessment

Executive 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 variety 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.

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Maine Climate Divisions & Growing Season Length, 1850-2000

Northern
39.31°F
41.13 inches

Southern Interior
43.15°F
44.12 inches

Coastal
44.30°F
46.49 inches

Northern

Southern Interior
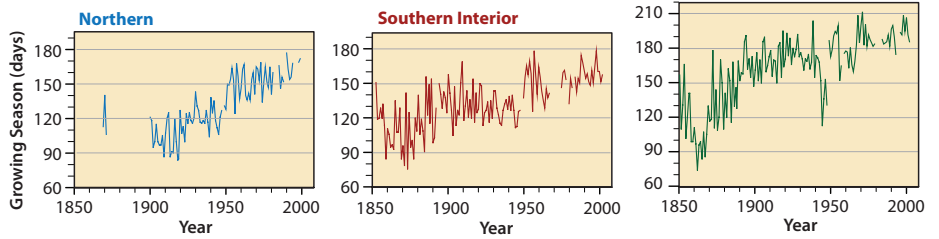
Coastal

Growing Season (days)

Figure 1. Left: 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. Above: 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.

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 (*Figure 1*). Regional sea surface temperatures have increased almost 2° Fahrenheit since 1970, and the rate of sea-level rise has intensified (*Figure 2*). 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 (*Figure 3*), 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 U.N. 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 Timing of Maine River Flows, 1952-2007

Winter | Spring | Early Summer

① Little Androscoggin River near South Paris
② Sheepscot River at North Whitefield
③ Piscataquis River near Dover-Foxcroft
④ Narraguagus River at Cherryfield
⑤ St. John River below Fish River at Fort Kent
⑥ St. John River at Ninemile Bridge

■ Increasing flows
■ Decreasing Flows

Jan 1 | Feb 1 | Mar 1 | Apr 1 | May 1 | Jun 1 | Jul 1

Figure 3a Stream gauges across the state 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).

Moosehead Lake
Sebec Lake
Rangeley Lake
Richardson Lakes
Cobbosseecontee Lake
Damariscotta Lake
Auburn Lake
Sebago Lake

1. Little Androscoggin
2. Sheepscot
3. Piscataquis
4. Narraguagus
5. St. John
6. St. John

Maine Sea Level, 1912-2100.
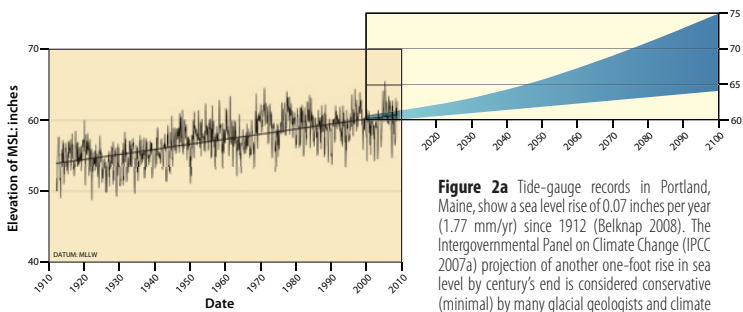
Elevation of MSL: inches

DATUM: MLLW

Figure 2a 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).

Sea Surface Temperature in the Gulf of Maine

Sea Surface Temperatures Relative to 1961-1990 Average (°F)
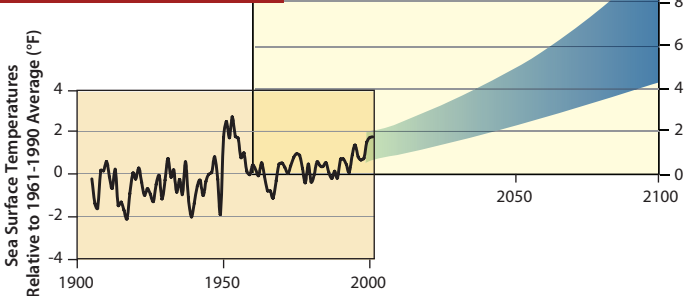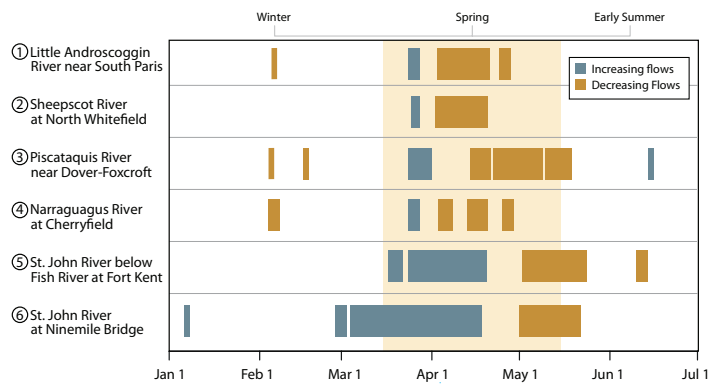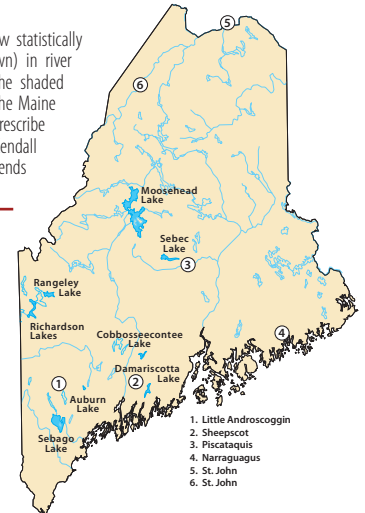
Figure 2b Observed and predicted sea surface temperature anomaly (relative to 30-year average) at Boothbay Harbor (observational data from M. Lazzari, Maine Department of Marine Resources; predicted range based on Frumhoff *et al.* 2006).

Ice-out Records for Selected Maine Lakes

Julian Date of Ice Out

Rangeley
Moosehead
Richardson
Sebec
Sebago
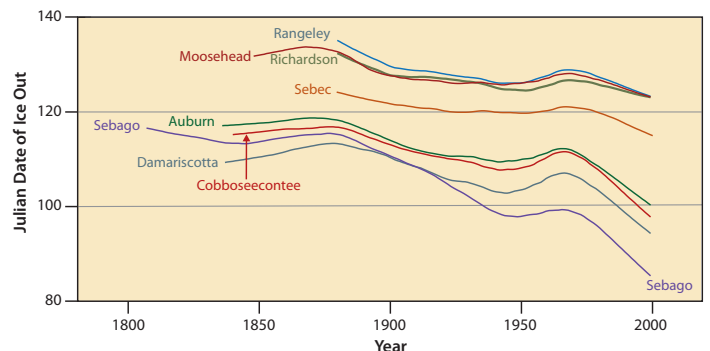Auburn
Damariscotta
Cobbosseecontee
Sebago

Figure 3b 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).

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 (*Figure 4*). A warmer and wetter future will affect all 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 (*Figure 5*). 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.

Current and Projected Forest Cover in the Northeast
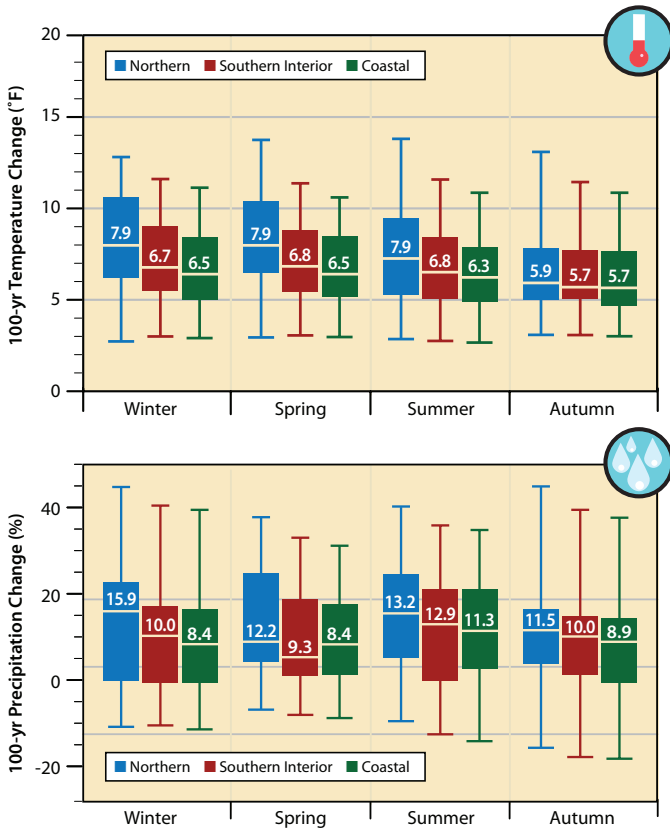
Maine's Future Climate

Figure 4 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.
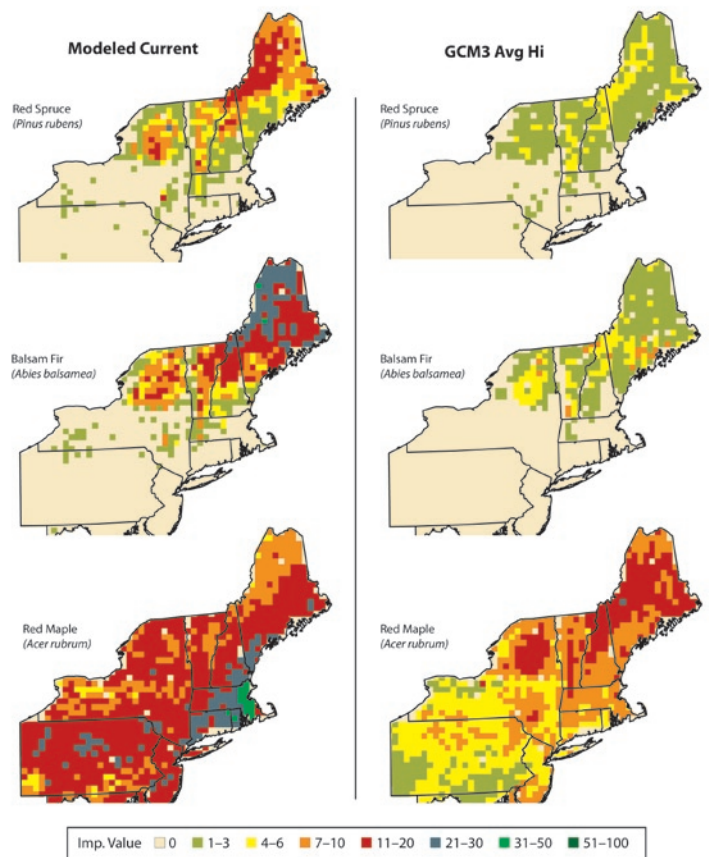

Figure 5 Maps showing modeled current and predicted future ranges for three important Maine tree species based on Forest Inventory and Analysis (FIA) data (Prasad *et al.* 2007) and 38 predictor variables. Future model projections were made using the average of three general circulation models (CM3Avg 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.