CHAPTER 5

CLIMATE IMPACTS ON REGIONAL FORESTS

By Gary Lauten, Barrett Rock, Shannon Spencer, Tim Perkins and Lloyd Irland

Introduction

Every autumn in the New England region is spectacular as broadleaf trees begin a transformation, their leaves turning brilliant hues of red, purple, orange, yellow, and brown. This artist's palette of brilliant colors occurs between mid-September and late October and is responsible for a very busy tourist season throughout the region. This seasonal display is however vulnerable to future climate change variables (air quality, seasonal dynamics, species migration, and extreme weather events) because the quality and brilliance of the display is dependent on tree health, temperature variation, and the species present.

While the regional forests are a major source of livelihood to the inhabitants, this chapter will highlight the impacts of climate on the fall foliar display. It is also important to recognize that as the forest conditions change in response to climate, wildlife habitats will also change. The current assessment of the impact of potential climate change on regional forests did not include a wildlife component, but rather focused solely on the forests themselves.

Soil type and moisture, site quality, species characteristics and composition, and tree health are factors known to vary the quality, intensity, and duration of the annual display. However, climatic factors play an even more significant role, since hard frosts hasten the loss of chlorophyll and enhance the colors of the other pigments. All these factors complicate the ability to predict a good or bad foliage season. The year 1998 was the warmest on record, both for this region and the globe. Delayed killing frosts in November or December of that year led to trees keeping their leaves longer than usual, and the colors were delayed and muted in many parts of the region.

In addressing the potential impacts of climate change, current stresses on regional forests, and how these stresses may be exacerbated by future climate changes are considered. In addition, potential benefits which might derive from climate change, as well as coping strategies and missing pieces needed to more fully characterize impacts are identified. Four case studies are presented which document the impacts of current stresses on forests and potential impacts under climate change scenarios.

Current Stresses and the Impact of Climate Change

Warm temperatures allow insects and diseases to flourish and permit the introduction of exotics not previously found in the region. Currently, the northward spread of the hemlock wooly adelgid is accelerating because of mild winter temperatures. This insect has caused major damage to hemlock stands (a favorite home to deer) in southern New England and has recently spread to the northern Massachusetts border. Warmer temperatures may increase the severity and occurrence of gypsy moth (which attacks the leaves of oaks and other broadleaf species) and pear thrip (which attacks sugar maple foliar buds) outbreaks.

Air quality also has an impact on tree health and thus ultimately affects leaf color. Warm, dry summers increase concentrations of ground-level ozone known to cause cellular damage in

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leaves (see Case Study #1). Acid precipitation can cause nutrients such as calcium and magnesium to be leached from the soil. When these nutrients are removed, harmful elements such as aluminum may injure roots. It is important to note that an increase in carbon dioxide from fossil fuel emissions may act as a fertilizer and enhance growth. Such a fertilizer effect must be balanced against the damaging effects of poor air quality and nutrient depletion.

Ice storm damage (see Case Study #3) has had a significant impact on selected tree species. Trees which were less flexible (maples and oaks) tended to be more heavily impacted due to breakage than those species which were more flexible (pines and birches). The damage caused by the 1998 ice storms is an example of one climate variable that has had an impact on maple sugar production across the region (Case study #2).

Finally, species migration due to a changing climate may well be the most devastating impact to affect regional forests. The climate models predict that by 2100 the major components of the New England forests will be oak and hickory (see Case Study #4). The brilliant reds, oranges, and yellows of the maples, birches, and beeches may be replaced in the landscape by the browns and dull greens of oaks.

Air Quality Issues

Tropospheric or ground-level ozone (i.e. not stratospheric ozone) is one of the most pervasive and detrimental air pollutants known to affect forest growth. As was noted in Chapter 1, a strong correlation has been shown to exist between changes in physical climate (temperature) and changes in the chemical climate (air quality), notably in the production of elevated levels of ground-level ozone. Studies have shown that the most pronounced affect of ozone on plant carbon uptake is a reduction in net photosynthesis due to a loss of chlorophyll and photosynthetic enzymes. Due to the documented effects of tropospheric ozone on both vegetation health and human health (the Hiker Health Case Study, Chapter 7), improving our understanding of the variations in regional tropospheric ozone levels and changes in forest and ecosystem health is a goal of present regional research efforts.

Due to the topographic variability typical of the region and the fact that it is downwind from the rest of the country and parts of Canada, upper-elevation sites (generally above 3,000') are sometimes characterized by unhealthful levels of anthropogenic ozone. Long-distance transport of NO_x, combined with both high levels of naturally-occurring VOCs (terpenes from trees) and sunlight at high elevation combine to produce elevated levels of ozone (above 80 ppb) during much of the summer season. These elevated levels of ozone can lead to significant problems for trees, but just as significant is the finding that sensitive tree species can be affected by ambient levels.

Seasonal Dynamics Issues

Based on the regional scenarios generated using the Canadian Climate Model and the Hadley Climate Model, the New England region is likely to experience a warming trend and an increase in precipitation over the next 100 years. Both climate models suggest future warming

The climate models also project warmer minimum (nighttime) temperatures that could affect tree physiology…

by 2095, but to differing degrees (an increase of 5.2° C/10.0° F, based on the Canadian model and 3.1° C/6.0° F based on the Hadley model). In terms of precipitation, the models differ as well, suggesting a 5-10% increase based on the Canadian and a 28% increase based on Hadley models. In both models, minimum temperatures increase at a greater rate than maximum temperatures over this time frame. Such changes could have a profound affect on seasonal dynamics across the region: milder winters (especially warmer nighttime temperatures); warmer and wetter summertime conditions; etc. Such changes would have dramatic, potentially negative effects on forest and wildlife habitats that typify New England.

Extreme Weather Events

Although the links between regional climate patterns and the frequency/occurrence of extreme weather events are not well documented or understood, the warming trends and increased precipitation patterns suggested by both Canadian and Hadley models may lead to more extreme weather events such as ice storms and droughts across the region.

Impacts of Future Climate Change

Seasonal Dynamics

The climate models used in this study suggest that warm temperature will persist longer into the fall. This could mean that the leaves would just turn color later in the year, or as the fall of 1998 suggests a reduced color display. Species that are more dependent on temperature would change color later than those species that are more dependent on day length, again producing an uneven display. The climate models also project warmer minimum (nighttime) temperatures that could affect tree physiology (increased respiration rates would cause loss of sugars retained in the leaves), also leading to reduced color display.

Air Quality Issues

In addition, the warming trends projected by either climate scenario could mean an increase in the number of hot, dry days during summer months, especially in the case of the Canadian Model. Such an increase would result in more ozone exceedance days thus affecting sensitive forest species such as white pine (Case Study #1). Reduced air quality will be a byproduct of a warming trend across the region.

Insect Pests

In much the same way as the northward incursion of the hemlock wooley adelgid, a warming New England region (especially warming winters) would promote the introduction and expansion of exotic pests into the region. Insect pests such as the gypsy moth and the pear thrips could become more aggressive and have an even greater impact on regional forests than is currently felt.

Species Migration

Both the increase in air quality impacts and attacks by insect pests would combine with environmental changes associated with a warming scenario to facilitate species migrations into and out of the region. As shown in Case Study #4, species more tolerant of these conditions would replace less tolerant species over time, resulting in forest composition changes into the future.

…the most effective approach for coping with change will be to anticipate the effects of that change and initiate adaptation strategies.

Potential Benefits

Forests dominated by oak and hickory may provide a commercial benefit to the region. Increasing levels of CO_2 in the atmosphere will likely act as a fertilizer, enhancing forest growth. In addition, the longer growing seasons may result in increased forest productivity. Recent research has shown, however, that such increased growth may be limited by soil nutrient levels in which elements such as calcium may be leached due to acid rain. Thus, on balance forests in the region are likely to become less healthy, due to insects, poor air quality, and nutrient depletion, in spite of the CO_2 fertilization affects of enhanced greenhouse gas levels.

Coping Strategies

Since there is very little that can be done to stop the impact of climate change on the forest ecosystem, the most effective approach for coping with change will be to anticipate the likely effects of that change and initiate adaptation strategies. Educating and preparing both the general population and specific forest sector industries for the impending change will require such strategies.

Land use policies and conflicts will most likely become major issues as the climate changes. There will be pressure from shifts in land use, whether it be urban sprawl or increased agricultural activities, that will encroach on the natural ecosystems. It will be important to maintain contiguous forest regions and not continue the current land use practices that foster fragmentation of the landscape with subsequent impacts on wildlife. Community, county, state, and regional planners need to make educated decisions that balance all stakeholder needs.

Climate change will likely result in more severe and numerous infestations of current pests and pathogens as well as those that will invade in the years to come. Pest management practices will need to be reconsidered and integrated pest management programs revised to fully address these problems. This may well include the need for the use of pesticides in order to sustain forests that will be weakened from air pollutants, drought, and warmer temperatures.

A shift in species composition, invasion of exotic species, and loss of some habitat will require the most adaptation strategies. Some species, such as oak, hickory, beech, and sweet gum will be less affected since they are far from their northern ecological limit, while other species, such as fir, spruce, aspen, and sugar maple are near their southern ecological boundary and more sensitive to change. The forest products industries need to address a number of adaptive measures to insure continued economic prosperity as species composition changes, since these industries traditionally need a 25-30 year lead time on capital investment. Specific coping strategies include:

- Planting different species after harvesting current stands. Warmer climate species have a faster growth rate that could increase productivity.
- Forest fertilization may become necessary as forest soils are altered by changing water chemistry and warmer temperatures.
- The industry should look at possible product diversification and more altered harvesting and marketing strategies.

Information and Research Needs

In conducting this initial assessment, missing information and basic research needs were identified. Regional stakeholders are aware that the forest sector is particularly sensitive to climate change, but they feel that they do not fully understand or appreciate the issues involved. To better understand these issues the following needs are suggested:

- Prioritize research and education programs that focus on the regional impacts of climate change.
- Improve the resolution of climate models so that climatic factor variability scenarios can be created for specific areas of the region. These models should include physical and chemical climate factors and current land cover and land use change information.
- Identify environmental thresholds (critical changes in factors such as temperature, precipitation, air pollutants, etc.) beyond which an individual species or ecosystem can no longer function.
- Quantify, in terms of dollars, the impact to natural and managed ecosystems for the various climate scenarios, determining the true economic impacts of climate change on this sector.
- Improve current techniques for improving the soil quality in managed forests.
- Identify genetically selected species or varieties with adaptive traits for changing climatic conditions.
- Better prediction of extreme weather events. Since ice storms, for example, are controlled by localized meteorological conditions, elevation, land cover, and aspect, results of the new regional models will be very useful for predicting events at local scales.

CASE STUDY 1

Forest Health and Productivity in Response to Ozone Exposure in a Sensitive Species

by Barrett Rock and Shannon Spencer

White pine *(Pinus strobus)* is a forest species that occurs across New England. Commercially, it is an important timber species for the region and is one of our most common low-elevation conifers. White pine is also known to be a bio-indicator species for exposure to high concentrations of tropospheric ozone, a common component of SMOG. Diagnostic foliar symptoms, known as chlorotic (yellow) mottle and tip necrosis (browning) (Fig. 5.1), occurring in the absence of other known causes, are likely to result from exposure to ozone levels at or above 80 parts-per-billion (ppb). Such symptomology is the result of varying degrees of chlorophyll loss. Such chlorophyll loss leads to a reduction in net primary productivity (NPP), which in turn can lead to a reduction in wood production in sensitive species such as white pine. A reduction in NPP due to exposure to elevated levels of ozone (above 80 ppb) across the New England region will result in a loss of timber productivity leading to a loss in the forest's ability to sequester carbon.

An on-going science outreach program called Forest Watch, developed by researchers at the University of New Hampshire, engages pre-college students across New England in studying forest health, with a specific focus on white pine. Forest Watch students collect needle and branch samples from five white pine trees located near their schools for study in their classrooms. Branch collections are made in the spring of each year, resulting in needle samples representing the previous summer's growth. Each year, branch samples with the previous year's needles are sent to the University of New Hampshire for spectral characterization using a reflectance spectrometer.

Chlorophyll variation can be quantified using spectral reflectance measurements acquired using field and laboratory spectrometers. One of the spectral parameters, the Red Edge Inflection Point (REIP), is computed for each set of needles sent by the students. Since the REIP is highly-correlated with foliar chlorophyll content (high REIP values correlate with high chlorophyll content, low REIP values correlate with low chlorophyll levels), it may be used as an indicator of needle health.

The annual REIP values for white pine from students have been correlated with summer (June, July, and August) ozone values for seven locations monitored by the New Hampshire Department of Environmental Services around the state (Figure 5.2). These monthly maximum values are reported by the Environmental Protection Agency (EPA) on their Web site for each monitoring station.

Figure 5.3 shows the inverse relationship between the spectral measure of chlorophyll and ozone data in New Hampshire for the years 1991-1998. The resulting correlation coefficient is very significant with an r^2 =-0.81, meaning that 81% of the variation in spectral values are correlated with variation in ozone.

The data presented in Figure 5.3 indicate that when average ozone values are high for a given three-month summer period, the chlorophyll levels and inferred health are low. Conversely, when ozone values are low for a given year, the spectral values from the same 30 trees suggest healthier conditions. The higher the REIP value, the healthier the needle samples. This documents an adverse relationship between ozone and the health of the

FIGURE 5.1
Typical foliar symptoms of ozone damage seen in white pine needles.

Clearly, the elevated levels of ozone anticipated as a response to future warming could have a significant adverse impact on sensitive species.

needle samples that varies from year to year. It is important to note, however, that in science correlation does not equal causation. Other climatic factors such as rainfall during summer months and the timing of precipitation have been compared against the REIP values and are not considered to be significant variables. Because high temperatures during summer months and ozone formation are correlated, high temperatures and REIP values also show a similar inverse relationship.

What does the Health of White Pine tell us about regional air quality?

Ozone impacts white pine, and other tree species, by entering the stomates and oxidizing (breaking down) the living cellular membranes, along with chloroplast membranes. In previous controlled-exposure studies, exposure of needles to levels of ozone above 80 ppb resulted in cellular degradation and chlorophyll loss resulted in lower REIP values. There is an overwhelming theoretical basis for the assumption that exposure to elevated levels of ozone will cause loss of chlorophyll in white pine. Controlled exposure studies conducted at Acadia National Park also support the view that white pine is very sensitive to exposure to elevated levels of ozone.

In a simulation study of the potential impact of tropospheric ozone on forest productivity, researchers combined leaf-level ozone response data from a series of ozone fumigation studies of appropriate species, with a forest ecosystem model in an attempt to quantify the affects of ambient ozone on mature hardwood forests across the New England region (including upstate New York). Using ambient ozone data for the region from 1987-1992, predicted declines in forest productivity ranged from 3-16%, with the greatest reductions occurring in the southern parts of the region characterized by the highest ozone levels, and in those species most sensitive to ozone.

These results demonstate the high degree of variability in air quality across the region, and in the biological response to this variation from year to year. Clearly, the elevated levels of ozone anticipated as a resonse to future warming could have a significant adverse impact on sensitive species.

Locations of the Original Ozone Monitoring and Forest Watch Study Sites

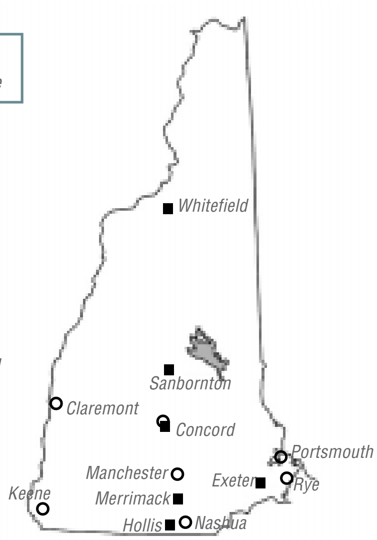


FIGURE 5.2
Seven locations where ozone is being monitored by the New Hampshire Department of Environmental Services plus the six Forest Watch schools.

Mean REIP and Mean Maximum Monthly (June-August) Ozone Concentration 1991-1998

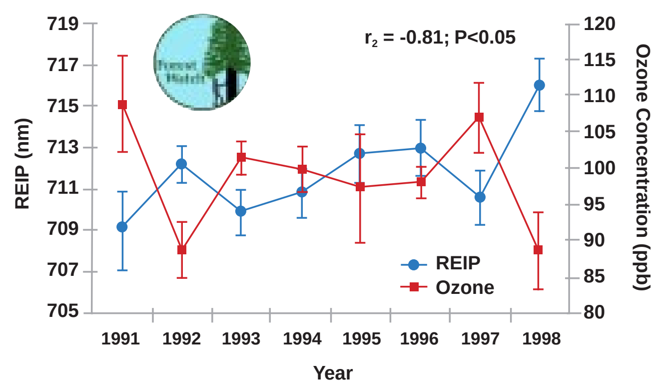


FIGURE 5.3
Inverse relationship between the REIP and ozone data in New Hampshire for the years 1991-1998.

CASE STUDY 2

The Maple Sugar Industry

by Barrett Rock and Shannon Spencer

The maple sugar industry represents an important component of both New England and New York's character and economy. The U.S. maple syrup production presently accounts for approximately 20% of the worldwide production. Prior to the 1950s, the U.S. accounted for 80% of the worldwide maple syrup production. The New England/ New York region represents roughly 75% of the total U.S. production and the average value of the New England/New York syrup production was $25 million for 1997-1999 (Figure 5.4). In Vermont, the highest volume maple syrup producing state in the region, the multiplier affect of the industry to related equipment, manufacturing, packaging, and retail sectors equals $105 million annually and represents approximately 4000 seasonal jobs. The maple syrup industry also contributes significantly to the tourism industry and other service sectors within the region.

The sugar maple tree *(Acer saccharum)* produces sap flows during late February to early March depending on geographic location and diurnal (day/night) temperature differences. This occurs due to physiological changes resulting in the conversion of stored starch to transportable sugar (sucrose). Sucrose is required for bud and leaf expansion and prolonged cold periods below 25ºF (cold recharge periods) are required for the enzymatic conversion of starch to sucrose, resulting in high sugar content (3-5%) in the sap. The occurrence of diurnal alternating freeze-thaw conditions causes positive stem pressures, resulting in sap flow. Amino acids found in the sap, microbial action, and thermal carmelization are responsible for giving maple syrup its distinctive color and taste.

The successful maple syrup season in New England depends on the proper combination of freezing nights and warm daytime temperatures greater than 40° F. Once a string of days occurs where nighttime temperatures no longer fall below freezing, sap flow stops. The first sap flow of the season generally has the highest sugar content and the lowest nitrogen content, resulting in the highest quality syrup of a given season. Therefore, the maple industry in New England depends to a large extent on the timing of these critical climate events. For Vermont this has typically been between the middle of March and the middle of April. Yet, for the last several years the sugaring season and first sap flow have occurred as early as the beginning of February. Warmer seasonal temperatures result in reduced sap flow, a shorter tapping season, and a lower grade product. The question that concerns New England regional maple syrup producers in the NERA region is: How will a changing climate affect sap flow and quality?

Current Stresses on the Syrup Industry

Tree health issues dominate the concern for most maple syrup producers in the region. In 1987 the North American Sugar Maple Decline Project, now named the North American Maple Project (NAMP), was formed out of concern for an apparent regional decline in sugar maple health. A number of biotic (pests, pathogens) and abiotic (acid rain, soil depletion) stresses are of concern. The primary biotic stressors include Pear Thrips, which had a significant outbreak in 1988, and

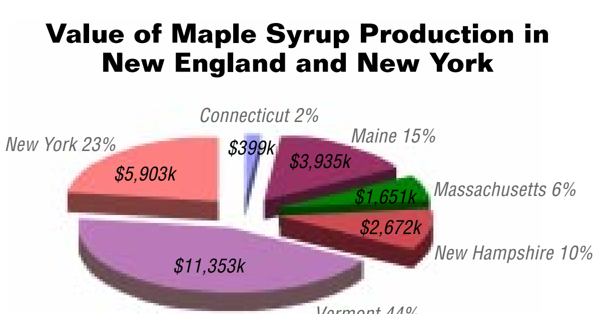


FIGURE 5.4
Average production value for New England states and New York between 1997-2000.

Early initial flows and warmer nighttime temperatures . . . have resulted in a shift in syrup production to the Gaspe Peninsula of Quebec.

the Forest Tent Caterpillar. These two insects affect the leaves of sugar maple during the spring and early summer which, when the outbreak is severe, can affect photosynthesis and the amount of stored stem and root sugars. Abiotic impacts to sugar maple include air pollution, atmospheric deposition, drought, and damage to stems and roots by humans. A bad drought year in 1988 significantly affected tree health for two years. Wet deposition of high levels of both sulfate and nitrate had significant impacts on maple health. Freeze injury to roots during periods of little to no snow cover may also be detrimental to tree health.

Climatic impacts, such as drought (mentioned above) and ice storms, can cause significant local and regional-scale maple tree damage, which can influence sap flow and syrup production. The Ice Storms of 1998 appear to have had significant impacts on maple syrup production and tree health in the New England/New York region (see Ice Storm Damage Case Study). In areas where maple stands were affected by the ice storms, moderate to severe damage occurred on 22% of the trees. Northern New York was severely affected by the ice storms and an average of 26% of the trees within damaged sugarbushes were severely damaged (80-100% crown loss). The Cornell Cooperative Extension Agency estimated the initial economic impact of the ice storms on syrup production in Clinton County, NY to be $4.5 million. The estimated 1998 syrup production loss for NY counties ranged from 20-100%. The damage caused by the storms includes direct structural damage to trees (broken limbs/trunks), damage to sap collection equipment, and a lost opportunity to tap trees where access to the sugarbushes was impeded by downed debris. The full impact of these ice storms will not be known for several years until tree recovery and sap production impacts can be fully assessed.

A recent study of two Vermont maple stands assessed the relative impacts of two growing seasons (1998 and 1999) on the root and stem carbohydrate reserves in sugar maple. Precipitation in 1998 was normal, while 1999 was a significant drought year. Year-to-year variations in precipitation between the two growing seasons resulted in greater difference in root and stem starch when compared with the effects of the ice storm damage. There was approximately 70% less root starch in 1999 (the drought year) when compared with 1998, and stem starch was 50% less in 1999 than in 1998. These results call into question the significance of severe weather events (the ice storms) and highlight the importance of inter-annual climate variation in terms of their impact on stored energy reserves in sugar maple.

Another current stress to the New England and New York syrup industry is market competition. Canadian production of maple syrup has tripled since the 1970s (figure 5.5) due to several factors, one of which is aggressive marketing. In addition the Canadian government now offers subsidies for Canadian syrup production. At the same time U.S. production has been constant. Market forces are making maple sugaring in New England more and more marginal, especially for small producers.

Finally, the advent of tubing-based methods of sap collection has also played a significant role in the Canadian dominance in the world maple sugar production. In the past, the success of the maple syrup industry in Canada was limited by deep snow cover (limiting access to individual trees) and fewer freeze/thaw cycles due to prolonged periods of low nighttime and daytime temperatures. The development of tubing-based sap collection methods that provide easier access to trees and early initial flows and warmer nighttime temperatures (fewer freeze/thaw cycles and reduced cold recharge periods) across New England over the past two decades, have resulted in a shift in syrup production to the Gaspe Peninsula of Quebec.

Current and Historic Syrup Production Trends

Syrup production for both the New England/New York region and other U.S. syrup producing states show a long-term trend in decreased production and more recent short-term variability (Figure 5.5). There are a number of factors that can account for these short and long-term trends in maple syrup production; some are climate related while others are socially or economically related.

From a climate perspective, there are two primary questions the industry needs answered regarding the impacts of a changing or variable climate in the future:

…approximately 30% of the variation in syrup production can be correlated with variations in January-April temperatures.

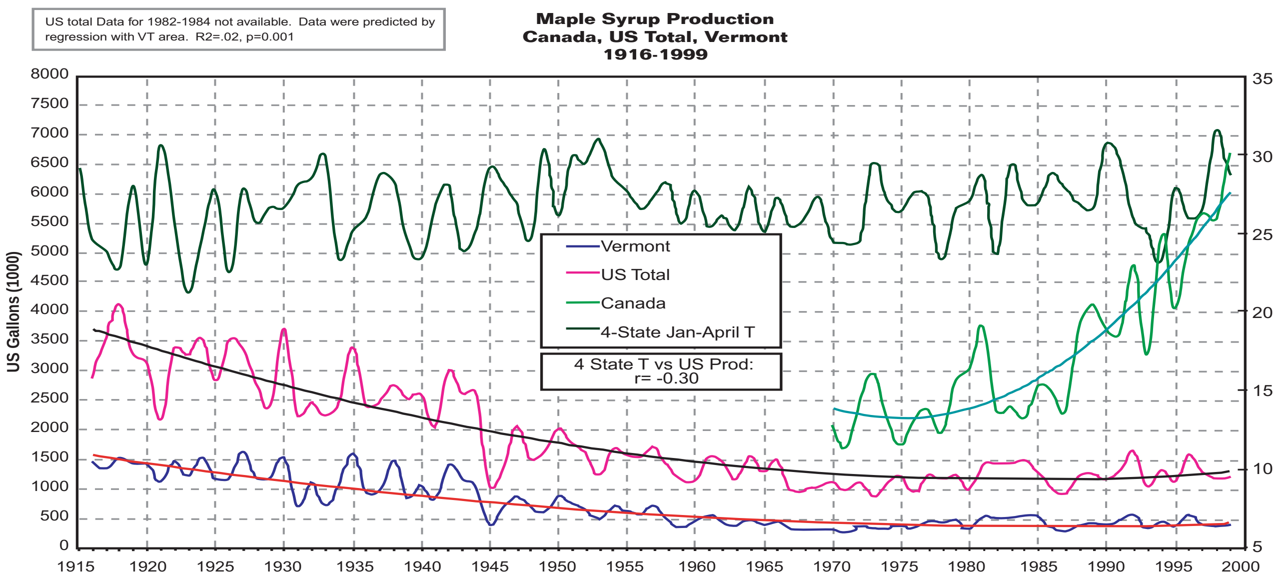


FIGURE 5.5 Maple syrup production: Canada, U.S. Total, Vermont 1916-1999.

1. What direct affect would a change in climate have on sap production?
2. What affect would climate change have on the health of maple trees in the region?

To address these concerns we must consider the various factors that affect maple sap flow and factors that affect syrup production. Poor climatic conditions may reduce sap flow, while a good sap flow year could occur but the number of trees tapped could be reduced for any number of reasons.

Figure 5.5 shows that U.S. syrup production has decreased dramatically since the early 1900s and has stayed fairly level over the last 30 years. Vermont, the largest U.S. producer, has also seen a decrease but this has been less dramatic than the U.S. total production. Since January to April is the timing for maple tree tapping and sap flow, mean temperature for this 4-month period for the four top producing states in the region (VT, NY, ME, NH in descending order) is plotted in comparison to syrup production. Interesting patterns are seen between the mean temperature data and Vermont, total U.S., and Canadian maple syrup production: In general, years with lower temperatures (e.g. 1998) exhibit an increase in syrup production. A moderate inversely related correlation ($r = -0.30$) between the mean temperature and total U.S. syrup production means that approximately 30% of the variation in syrup production can be correlated with variations in January-April temperatures.

Figure 5.6 shows the syrup production and mean winter temperature trends over the last decade. Three different ways of characterizing temperature data are plotted for comparison. The VEMAP temperature curve (see Chapter 4 for a discussion of these data) shows the mean of the monthly temperature between January 1 and April 30. Additionally, daily temperature data were acquired from one first-order station from each state and the daily data averaged over two time periods: January 1 to March 15 and February 1 to March 15. Some years show a relationship

The maple syrup industry in the US has exhibited a dramatic decline since early in the 20th century.

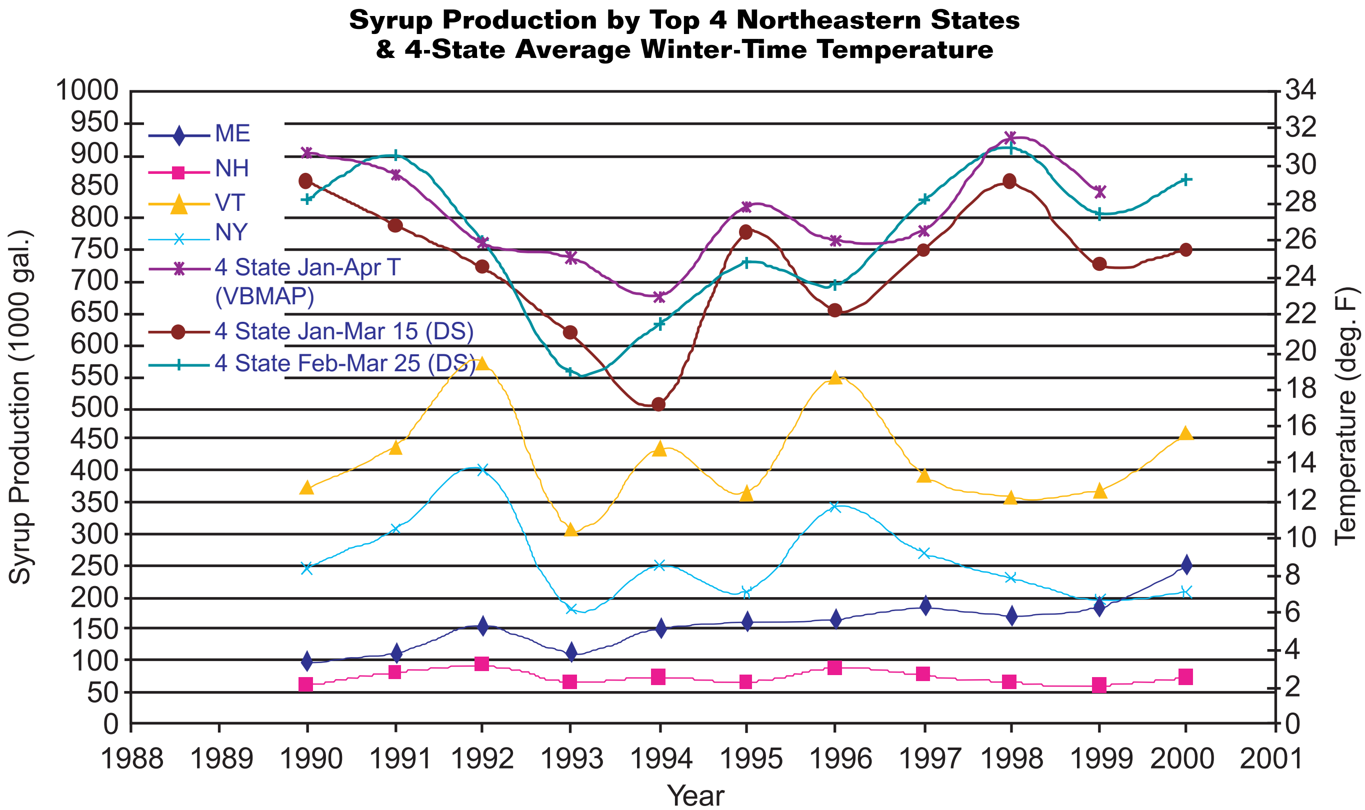


FIGURE 5.6 Recent syrup production and winter temperature trends in ME, NH, VT and NY.

with syrup production, with 1994 and 1996 "good" years corresponding to low temperature years. However, 1992 was a "good" year and 1995 and 1997 were poor years, yet all three exhibiting very similar temperature regimes.While ice storm damage may account for 1999 being a poor producion year in all states, both Vermont and Maine appear to have recovered in 2000 (unlike New York and New Hampshire.)

To accurately assess the impact of climate on syrup production, syrup production per number of trees tapped is needed. Additionally, precipitation and the previous summer's growing conditions are likely to have important implications for sap flow and syrup production during the late winter and early spring. The temporal analysis of climate data should be investigated further to better understand how climate variables and tree physiology control sap flow and quantity.

Conclusions

The maple syrup industry in the US has exhibited a dramatic decline since early in the 20th century. This decline is due to many factors, including climate. Over the past thirty years, the Canadian Maple industry has shown a dramatic increase also due to many factors, including climate. Most disturbing are the results of ecological modeling efforts that show the changes in climate could potentially extirpate the sugar maple within New England. The maple syrup industry is an important part of New England character, way-of-life, and economy that, because it is highly dependent upon prevailing climatic conditions, may be irreparably altered under a changing climate.

CASE STUDY 3
1998 Ice Storm Damage

by Shannon Spencer and Lloyd Irland

A major concern with a changing climate is the potential for an increase in the frequency and severity of extreme events in the New England region. As the New England Regional Assessment (NERA) process began, the ice storms of January, 1998 occurred, causing extensive economic and social disruption in northern New York, New England, and Quebec. This case study identifies and documents the impacts that current severe events, such as ice storms, have on the region.

Ice storms are not uncommon, but the meteorological conditions during the January, 1998 ice storms made them very geographically wide-spread (Figure 5.7) and devastating. The area of impact covered 4 states and Quebec, with 37 counties declaring Federal disaster areas (Figure 5.7). Extensive damage to forests resulted (Table 5.1). This particular event was categorized as a 200 to 500-year event with 17 deaths in New England/New York and 26 deaths in Canada. Approximately 1.5 million people across the New England/New York region were without power for up to three weeks. The economic impacts were well in excess of $ 1 billion in the U.S., and the long-term impacts of these storms are still being evaluated, especially the effects to natural and managed forest systems.

The conditions required for an ice event to occur are very specific. A temperature inversion must exist for an icing event to occur: a cold upper layer produces frozen precipitation, this falls through a warm layer at mid-altitude that melts the precipitation, this then enters a layer of cold air near the ground, which is below the freezing point. This super cools the precipitation. When this super cooled precipitation makes contact with the surface it freezes on impact, causing an ice glaze. If air temperatures near the ground are much colder than -3 degrees Celsius (26º F), then the precipitation freezes into sleet. Sleet bounces off surfaces rather than glazing them. Local variations in topography, elevation, aspect, and wind currents and speed influence the occurrence of ice glazing, resulting in patchy areas of ice glazing, as evidenced by the airborne mapping of damage in New Hampshire (Figure 5.8).

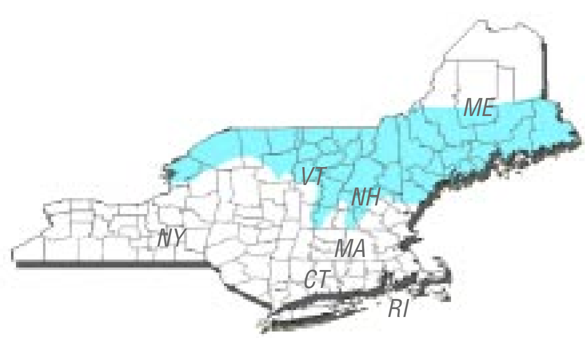


FIGURE 5.7 Ice-affected areas from January, 1998 ice storm.
Map produced by: USDA Forest Service, Forest Health Protection, Durham, NH 3/5/98

State	Area Impacted 1,000 Acres
New York	4600
Vermont	951
New Hampshire	1055
Maine	11000

TABLE 5.1. Forestland affected by 1998 ice storms

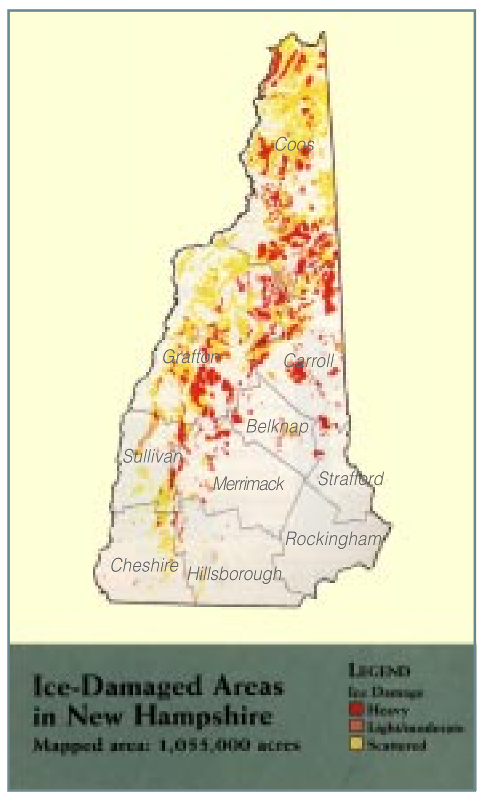


FIGURE 5.8. Sketch mapping of NH ice storm.

A standardized method of damage assessment for the entire region is needed.

Conditions for this inversion to occur include a stationary front that separates opposing air masses. The warmer air mass over-rides the cold air mass creating the cold-warm-cold temperature profile.

The National Weather Service (NWS) defines an "ice storm" as the occurrence of freezing precipitation resulting in the accumulation of 6.35 mm (0.25 inches) or more of ice. Ice accumulation typically occurs in limited areas traversed by a large storm due to the factors explained above.

Several major ice storms have been recorded in the climate record for the past century, with the following notable storms: 1909, 1921, 1929, 1942, 1950, 1951, 1953, 1956, 1961, 1964, 1969, 1976, 1979, and 1991. On average, 16 ice storms occurred each year across the U.S., from 1982 to 1994, making them more frequent than blizzards. A recent study has noted that several of the above mentioned storms were equal in severity to the 1998 ice storms, but that the geographic extent and duration of the 1998 event is unprecedented.

Concerns Regarding Ice Storm Frequency & Severity with Climate Change

The severity and wide-spread nature of the 1998 ice storms have led to questions about whether the New England region might experience increased occurrences of more extreme meteorological events, given a trend toward a warming climate; and, if so, what are potential consequences and/or mitigation steps needed to prepare for these damaging events? Though the answer to the first question at this point is not at all clear, we attempt here to address the major concerns by looking at our current knowledge of the situation.

Ice Storm Impacts on Forest & Natural Resources

Assessing the impact of historic ice storms and the 1998 ice storms can give us an indication as to the overall potential impact to the New England region if these events were to increase in a warming, more variable regional climate.

Significant damage to property, utility infrastructure and forest trees was recorded during the 1921 Great New England Ice Storm; over 100,000 trees were severely damaged. Such ice storms are usually a normal occurrence, from an ecological perspective, which have effects on forest species composition on a small geographic scale. Typically, greatest damage occurs in managed stands such as in plantations or heavily-thinned woodlots.

In the wake of the January, 1998 storms, an extensive effort was undertaken by state forestry agencies across the region to document forest impacts through aerial surveys and the study of ground plots. A common method of quickly assessing forest conditions is to conduct aerial sketch mapping using a trained observer to note crown conditions on a map. Another common method is to use a meteorological model to estimate damage.

Figure 5.7 shows the general areas affected by ice in the New England/New York region from the 1998 ice storm, while Figure 5.8 shows the specific damage sketch-mapped for New Hampshire. Power outage reports from public utilities may also be used to provide a rough proxy of the geographic distribution and severity of damage to forests and trees. Finally, detailed mapping based on interpretation of aerial photos may be used.

Based on measured impacts on forests, the degree of damage is typically highly skewed by state, due to assessment methodology. The Maine Forest Service initially assessed 1998 storm damage in broad areas based on assumed levels of damage due to a meteorological model, as defined in Figure 5.9. Comparing damage assessments for New Hampshire, based on sketch mapping (Figue 5.8), and Maine, based on a meteorological model (Figure 5.9), shows how the methodology can influence results. A standardized method of damage assessment for the entire region is needed. Based on previous work, satellite-based methods may provide such a standard assessment capability.

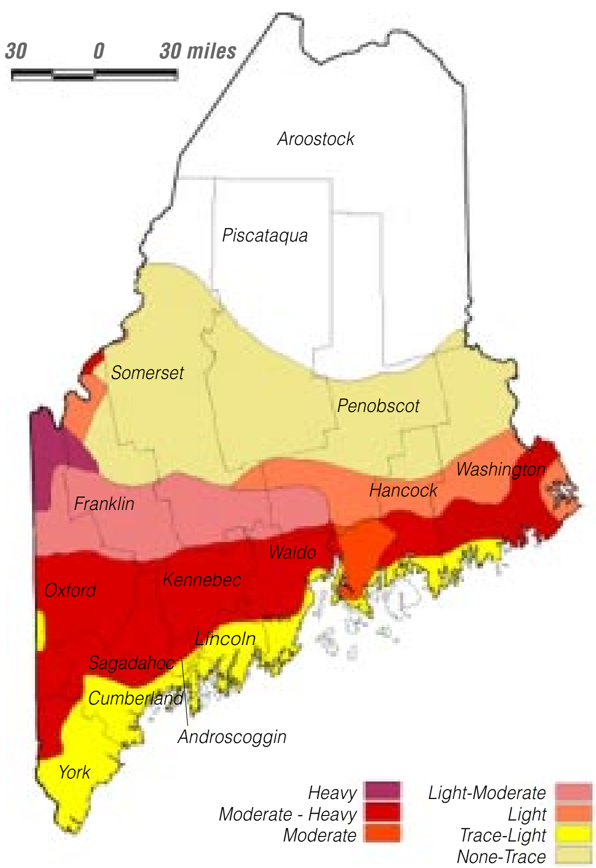
Field assessment during the following Spring and Summer of 1998 resulted in an improved understanding of the short-term forest damage and the geographical extent of the impact. Table 5.1 lists revised damage estimated from aerial photo analysis and field work. The extensive field work has provided a better understanding of the short-term forest

In general, more heavily managed (thinned) stands exhibited more damage than adjacent unmanaged stands.

impacts, as described below, but the long-term affects are still not well understood.

In the 1998 ice storms, icing lasted long enough that many trees, which were bent over due to the ice, had their crowns frozen to the snow/crust surface for as long as three weeks. In some instances, trees recovered to an erect posture after release from the snow, but most never recovered. Generally, softwoods seem to suffer less damage from the same degree of ice loading when compared with hardwoods and exotics and trees planted outside their natural ranges. Black Locust, and Willow suffered severely while nearby native species suffered far less damage.

Ice Damaged Areas in Maine



Map produced by Forest Health Protection GIS Group, NA SAFF, Durham, NH

FIGURE 5.9 Damage assessment map of Maine.

Depending on stand composition, amount of ice accumulation, and stand history, damage to stands can range from light and patchy to the total breakage of all mature stems. With moderate degrees of damage, effects on stands could include shifts in overstory composition in favor of the most resistant trees, loss of stand growth until leaf area is restored, and loss of value of the growth due to staining or damage to stem bending. In general, more heavily managed (thinned) stands exhibited more damage than adjacent unmanaged stands. It is possible that damage caused by sloppy salvaging could exceed the damage caused by the storm (trunk damage to a tree is far more serious than is branch breakage).

Forest damage tended to increase with increasing elevation and northern exposure; likely due to greater icing at elevations where temperature conditions promoted greater occurence of freezing rain. Figure 5.10 shows how the ice accumulation on canopy exposed twigs, along a transect at the Hubbard Brook Experiment Station, increased with elevation.

Impacts to Forest Recreation

The ice storms significantly damaged recreational trails in forested areas that were impacted. In the White Mountain National Forest, 850 miles of trails and roads were blocked with downed woody debris, while 257 miles of trails were impacted in the Green Mountain National Forest. Additionally, 6000 miles of snowmobile trails had damage. The damage caused is anticipated to affect future trail

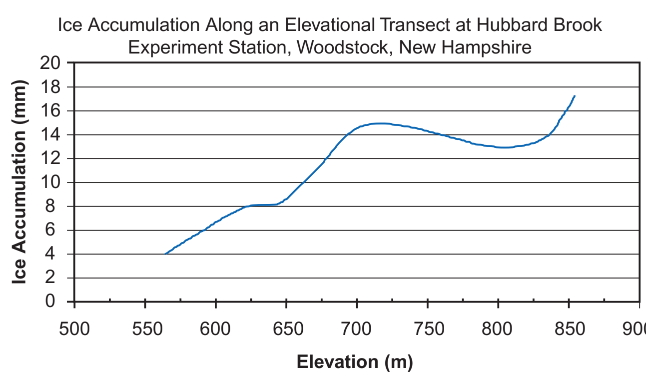


FIGURE 5.10 Elevational impact on icing.

Recovery has been substantial after two growing seasons on forest monitoring plots.

conditions as well. Less canopy cover in some steep portions are likely to result in increased erosion and waterbar washout. Additionally, the opening of the canopy will result in a flush of undergrowth that will require yearly clearing activity to those portions of the trail which were severely damaged. On the positive side, the canopy openings the ice storms created have encouraged increased wildlife activity. An increase in neo-tropical migrant bird species due to canopy openings may benefit bird populations. Increased understory forest growth has resulted in greater browsing by deer and moose, which will likely enhance a hunter's recreational experience.

Current Findings on Long-term Affects of the 1998 Ice Storm

Many studies to assess the impact of the 1998 ice storms on wildlife, ecological effects, and forest management activities are ongoing. Understory density has increased in the wake of the storms. A shift in species composition has also occurred. Recovery has been substantial after two growing seasons on forest monitoring plots in Vermont where significant foliage and crown damage were recorded in the summer following the ice storms. Greater downed woody debris, less canopy cover, less litter, taller herbs, and a greater amount of exotic species have been noted on ice storm damaged plots than on non-damaged forest plots, but tree mortality is not significantly different. Marked recovery is noted in even highly damaged trees after two years. Continued research and data analysis over the next five years will be important to achieve a full understanding of the long-term impact of the January, 1998 ice storms.

Implications for Natural Resources & Research Needs

Ice storms are frequent in the eastern U.S. and Canada. Storms of sufficient intensity to damage trees and forests occur in limited areas once every fifty years or less. Ice effects have been sufficient to affect stand composition in some areas. In today's younger, managed forests, the distinct effects of ice storms may be accentuated by management activities.

At present, it is not possible to predict how future climate change will affect ice storm incidence and severity. New research strategies, such as regional models, could shed light on this. At this point the best approach to handling the uncertainty in extreme events, such as an ice storm occurrence, is to be prepared to accept some level of risk. In general these events tend to be localized.

Lessons Learned

- The 1998 ice storms were unique in terms of recorded ice storms, due to the large spatial extent (NY, VT, NH, ME and Quebec) of the damage.
- The extent of damage to regional forests was heavy, affecting over 17,000 acres in the 4-state region.
- The economic impact on the forestry sector was approximately $400 million, including the $15 million impact on the maple syrup industry (which still continues).
- A standardized method of forest damage assessment does not exist and needs to be developed.
- Regional-scale climate models are needed to assess the impact of climate change on future ice storm frequency and severity.

CASE STUDY 4
Current & Future Potential Forest Cover Types

by Shannon Spencer

Species migration and forest cover type changes are potential issues in a changing climate. Yet, these are two very complex processes which relate not only to climate factors, but to human changes to the landscape, forest fire dynamics, disease occurrences, and geophysical attributes of the landscape, such as soil conditions, aspect (compass direction) and slope. This section takes a look at the current and potential forest cover type distribution for the New England/New York region.

Current Forest Types

The current forest types for the region, as depicted in Figure 5.11, consist primarily of maple, beech and birch in the western and central part, oak-hickory in the south coastal part and spruce-fir in northern Maine.

Forest Types of New England and New York

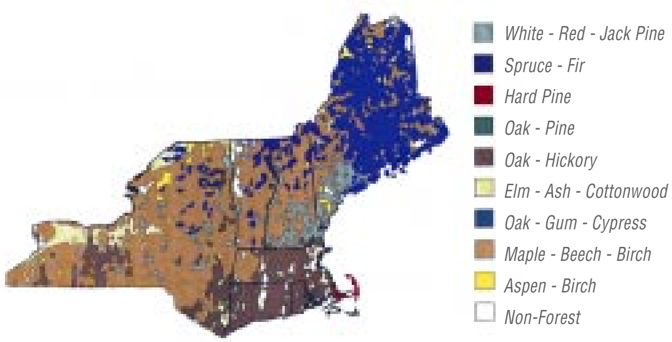


Figure 5.11 Current forest types.

Source: Adapted from USDA-Forest Service. 1993. Northeastern Area Forest Health Report. NA-TP-03-57pp.

This distribution of current forest cover types was established from USDA Forest Service Forest Inventory and Analysis (FIA) data, and the predicted potential forest cover types from modeling. The model investigates potential species importance values under a changed climate (doubled atmospheric carbon dioxide concentrations) using current species distribution and density data for the eastern US. The model is constrained by a species' ability to occupy an area, based on soil occurrence, landscape variables, land use, elevation and climate. To determine future abundance and distribution of over 80 tree species, an integrated regression model was used to predict Importance Values (IV) with several climate models (Global Circulation Models [GCMs]).

Future Forest Types

The IV model is based on several assumptions and uncertainties (such as future forest fragmentation impacts) and is therefore not an absolute prediction of future distribution. The approach provides a sensitivity analysis for possible ranges of tree distribution in the future based on predicted climate scenarios by global circulation models. Results from the authors' research predict that 30 tree species will expand their geographical range by more than 10% whereas approximately the same number of species will decrease their range by 10% or more. Four to nine species move out of the Eastern U.S., depending on the climate model used to force the Importance Value model. It was also found that for almost half of the species modeled, the biological optimum shifted more than 100 km, with seven species shifting as much as 250 km. The historic rates of migration, without human landscape fragmentation, is on the average of 10-50 km per 100 years, depending on species. Therefore, climate change could have very significant impacts on species migration and forest cover type distribution by the year 2100.

Figure 5.12 shows the current forest types as categorized by the FIA data and the IV model's predicted importance value

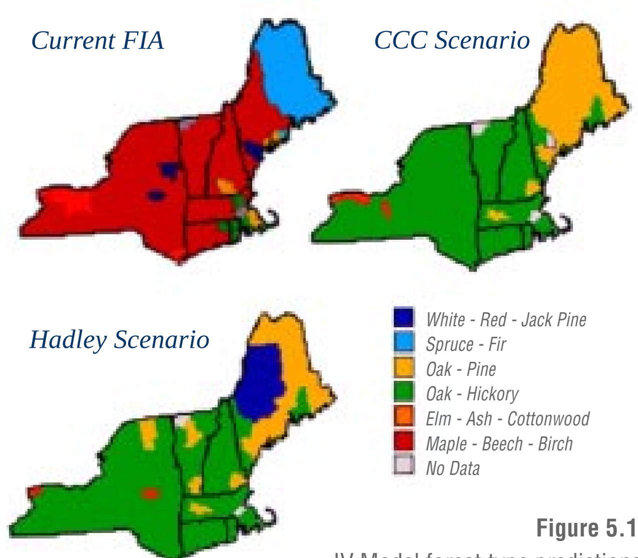


Figure 5.12
IV Model forest type predictions.
Adapted from Prasad and Iverson (2000).

Though these model results shouldn't be taken as absolute, they do indicate that the region's forest types may be very sensitive to changes in climate.

under a doubled CO_2 atmospheric environment. The results presented are based on the future climate predictions of the Canadian Climate Center and the Hadley global circulation models. The species importance values are presented for these two models because they are the ones used for the National and Regional Assessments. The IV model was forced by five different climate models in all, and very strong agreement was found for predicted potential species importance values in New England and New York (Figure 5.13). As can be seen by simple observation, significant changes in forest cover type are likely for the New England/New York region. Though these model results shouldn't be taken as absolute, they do indicate that the region's forest types may be very sensitive to changes in climate.

The impact of climate change on the top five dominant species was predicted by using the Canadian and Hadley models. In all cases maple becomes non-dominant, whereas currently it is one of the top two dominant species in all states. White pine appears to be relatively climate insensitive: in all states, but New York, its dominance increases. Since white pine is sensitive to ground level ozone, projected increases may be counteracted by poor air quality associated with warming. Oaks also become more dominant in a changed climate, while red oaks become less common.

This change in species dominance is rather dramatic and could have significant implications to both private and public sectors, as well as represent a change in the character and way-of-life of the region. Human land use changes have not been accounted for in this model, as they are difficult to predict, especially in a region dominated by small, non-industrial private landowners. Land use, especially forest fragmentation and development, could have negative impacts on species migration.

Continued research is needed to look at the effects of human landscape changes on species migration rates. Past climate changes associated with glaciation have been shown to affect species distribution, migration and forest composition at a regional scale. The question now is how will these forest species be effected by the rapid changes in climate projected to occur in the next 100 years? And, how will changes in forest type distributions affect the region ecologically, socially and economically?

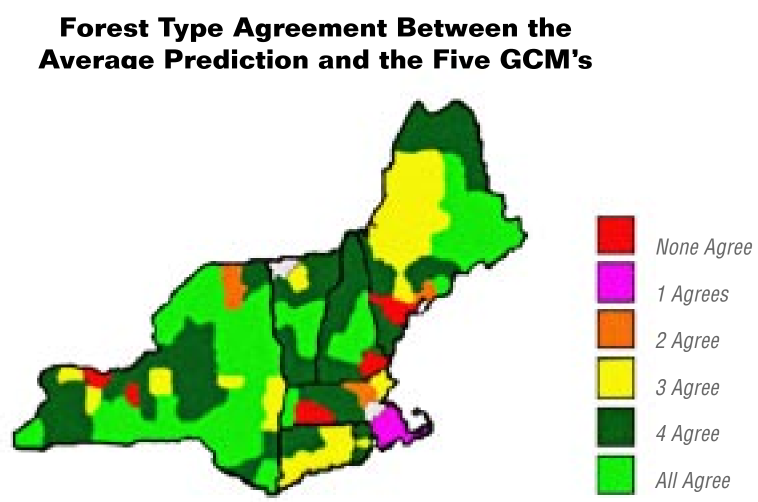


Figure 5.13 GCM model agreement in the prediction of species importance values.