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August 13, 1997

File:
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The Hon. Todd Stern
Staff Secretary
The White House
Washington, DC 20502

Dear Todd:

You may recall my mentioning EDF's upcoming report, "Seasons of Change: Global Warming and New England's White Mountains" at dinner at Senator Kerry's house on July 31. I enclose the final draft. The report, to be released at a press conference in Boston on September 2, discusses the potential ecological and economic impact of global warming on New England in general and the White Mountains in particular. Please note that the report is embargoed until September 2. The highlights include:

Disruption of the fall foliage season: Fall foliage displays could be muted due to an increase in dead and dying trees as climate changes. Eventually a change in tree species composition may occur, from northern hardwoods and conifers, like the brilliant red sugar maples and dark green spruce and fir to more southerly species like oak. Even earlier, if summer droughts become more common, as is predicted by some climate models, the quality of the display may dim. Some trees will drop leaves early, others may never produce vibrant colors before dropping.

A shortened ski season: The length of the ski season and therefore the success of the ski industry is inherently tied to weather. There is a potential for shorter ski seasons as a result of climate change though added investment in snowmaking could mitigate this somewhat. In the report, we discuss a scenario that shows a loss of 10 and 20% in the number of winter season days with a 3.6 and 7.2 degree Fahrenheit warming respectively.

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A dramatic decrease in trout habitat: According to a recent EPA study on recreational fishing, suitable habitat for cold-water fish including rainbow, brook and brown trout may be partially or completely eliminated in the White Mountains as well as other areas in northern New England if warming occurs as projected by the middle to end of the next century. Warmer air temperatures will lead to warmer stream temperatures eventually making habitat unsuitable for cold-water fishes. Lower water levels and reduced flows due to droughts could also decrease food availability and prevent fish migration to spawning grounds. Warm-water fish may have trouble colonizing these streams because they may be unable to tolerate the inherently fast stream flow rates found in the White Mountains.

We believe the report, the first in a series, will provide valuable perspective for citizens on the risks posed by climate change. If you have any questions, please feel free to call me. Since I will be unavailable part of the time between now and the release, you may also want to call Allan Margolin or Bill Roberts, both at EDF in NY.

Sincerely,

MO gp

Michael Oppenheimer
Chief Scientist

MO:gp
Enclosure

SEASONS OF CHANGE

Global Warming and New England's White Mountains

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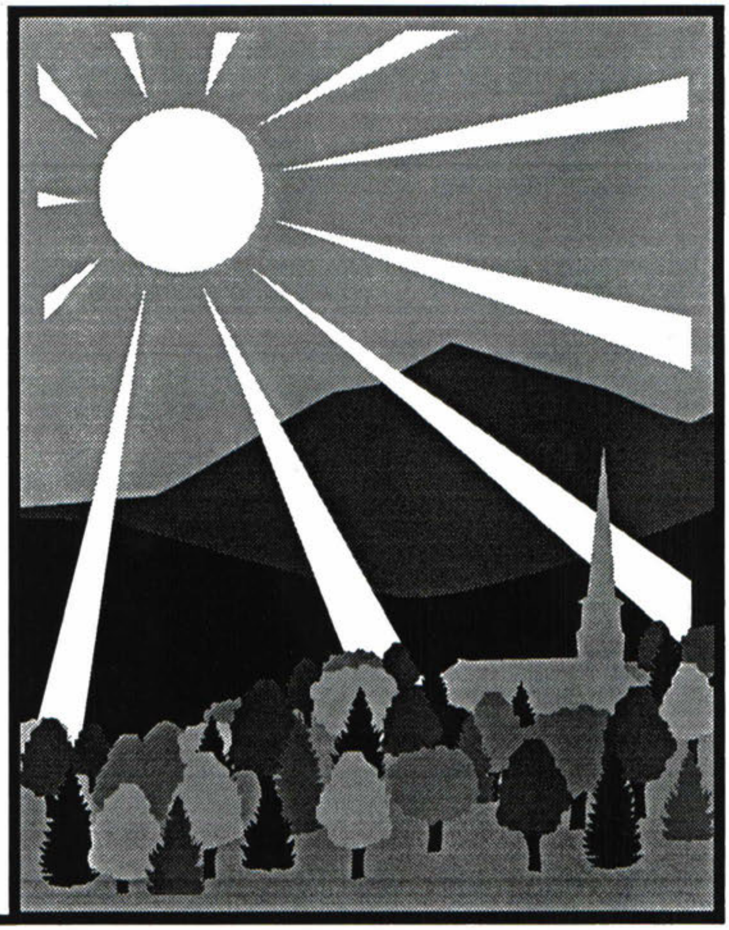


Global Warming and New England's White Mountains

ENVIRONMENTAL DEFENSE FUND

CONTENTS

EXECUTIVE SUMMARY

There is a scientific consensus that emissions of greenhouse gases arising from fossil fuel combustion, deforestation and agriculture have probably contributed to and will continue to cause global climate change. Current climate models used by the Intergovernmental Panel on Climate Change, an international group of more than 2,000 scientists, project that the Earth will warm by two to six degrees Fahrenheit by the year 2100. For New England in general and the White Mountains specifically, global climate change of this speed and magnitude could mean significant and, in some cases, significantly negative, impacts to its natural resources, health, and way of life. In addition to changes in forest and ecosystem types and productivity, there exists a significant risk of disruption of the fall foliage season, declines in maple syrup production, a shortened ski season, a dramatic decrease in trout habitat, and changes in the productivity of the timber industry.

While comprising a relatively small geographical area, the White Mountain region is home to a diverse selection of communities, local industries, and ecosystem types, all of which serve different segments of the regional and extra-regional economy in valuable ways. These include the long-standing traditions of timber management, maple-syrup gathering, and fishing, as well as the more modern economies of skiing, foliage viewing, and other tourism and outdoor recreation activities. Serving local working communities, businesses, second-home seasonal residents, far-flung visitors, and consumers from around the world, the White Mountains are a productive, well-known region of historical, natural, and economic significance. The continued importance of the White Mountains relies in large part on the persistence of historical climate patterns, which are now poised to change substantially over the next century.

By analyzing global and regional climate models, and the structure of local economies and ecosystem types, this study illustrates a variety of potential outcomes of *not* acting to slow climatic change that could affect the White Mountains region over the next few decades and century. Evidence suggests that the shorter winters; longer, drier summers; and increased frequency of flooding, winter thaws, and summer droughts associated with global warming, would be expected to occur in the White Mountains as well. These changes could have profound effects on the forest composition, water resources, snowfall, growing season, atmospheric visibility, local weather patterns, and ecosystem functions of the White Mountains.

These changes could lead to negative impacts on industries such as maple-syrup gathering, skiing, and fishing, and mixed, but likely negative, impacts on the overall tourism, recreation, and forest products industries. Quality of life and environment, although primarily subjective phenomena, are predicted to change dramatically as weather becomes more extreme, species composition changes, and economies are forced into rapid transitions.

The report considers in detail impacts on the following features:

Fall Foliage

The fall foliage season in the White Mountains brings visitors from around the world to view its brilliant natural display. The weekends during the fall foliage season, running between mid-September and mid-October are often the busiest of the year for the tourist industry. This display is susceptible to climate change in a variety of ways. The existing forests are vulnerable to decline as a result of climate change. Higher numbers of dead and dying trees would mute the hillsides of brilliant colors. As climate change continued, trees from further south are projected to start to replace the northern hardwood and spruce/fir forests leading to changes in the colors visitors see, such as more brown oaks and less brilliant red sugar maples and dark green evergreens. Even earlier, if summer droughts become more common, as is predicted by some climate models, the quality of the display may dim. Some trees will drop leaves early, others may never produce vibrant colors before dropping.

Ski Industry

The ski industry in New Hampshire plays a significant role in the state's economy and especially in the economy of the White Mountains region. Direct spending by ski area visitors in New Hampshire during the 1995-96 ski season totaled nearly $190 million, 8.6 percent of the state-wide total for direct visitor spending. The length of the ski season and therefore the success of the ski industry is inherently tied to weather. There is a potential for shorter ski seasons as a result of climate change though added investment in snowmaking could mitigate this somewhat. One scenario shows a loss of 10 and 20% in the number of winter season days with a 3.6 and 7.2 degree Fahrenheit warming respectively.

Recreational Fishing

According to a recent EPA study on recreational fishing, suitable habitat for cold-water fish including rainbow, brook and brown trout may be partially or completely eliminated in the White Mountains as well as other areas in New England if warming occurs as projected by the middle to end of the next century. Warmer air temperatures will lead to warmer stream temperatures eventually making habitat unsuitable for cold-water fishes. Lower water levels and reduced flows due to droughts could also decrease food availability and prevent fish migration to spawning grounds. Warm-water fish may have trouble colonizing these streams because they may be unable to tolerate the inherently fast stream flow rates found there. In the EPA model, the worst case result showed that nationally, the number of cold- and cool-water fishing days (defined as person-days spent fishing) declined by 50 million while the number of warm-water and rough guild fishing days increased by 64 million. However, because of the greater economic value of cool- and cold-water fishing there was a net annual loss of $320 million nationally.

Hiking and Nature Walking

The White Mountains region is a mecca for hiking and summer-time recreation attracting millions of visitors from sightseers to mountaineers with its spectacular peaks, alpine meadows, and verdant forests. The summit of Mount Washington, found within the borders of the White Mountain National Forest, is one of the most popular vistas in the world. While global warming will probably lead to a longer hiking season for the White Mountains region, it might also be much less enjoyable due to hotter, and potentially drier, smoggier summers and larger areas with dead and dying trees. Ground level ozone is already a problem in the White Mountains region. An Appalachian Mountains Club study has shown that ozone in this area is comparable to that of urban areas in southern New England. Higher heat will exacerbate this further. High ozone levels are damaging to both human and forest health. With warmer temperatures and altered climate, the types of forest trees in the region are predicted to change. High elevation spruce and fir may disappear early followed by susceptible members of the northern hardwood forest community. The process of forest decline may include increases in pest and pathogen outbreaks and more frequent forest fires. Eventually new forests may become established but during the time of transition, there may well be large amounts of dead and dying trees making for a more open but significantly less attractive forest for recreation.

Maple Syrup Industry

Sugaring, the harvesting of sugar maple sap to produce maple syrup, is a tradition in the White Mountains region and throughout New England that dates back to pre-colonial days. To residents and tourists alike, it wouldn't be spring in New England without the Maple syrup season. Sugar maple sap flows best when night temperatures are cold (less than 25°F) and day temperatures are relatively warm (greater than 40°F). But both the records of the last century and some climate scenarios for future warming suggest that temperatures may warm more at night than during the day. This could significantly decrease the number of days for sap flow. Scenarios of temperature increases of 3.6°F and 7.2°F with warming occurring predominantly at night resulted in a decrease in the number of optimal sap flow days by 17 and 39% respectively.

Sugar maple are also susceptible to mid-winter thaws and summer drought, which may accompany climate change. When snow cover is lost during the winter through a mid-winter thaw, sugar maple's shallow roots can be killed when temperatures drop again. Large-scale die-offs or declines have occurred during the last century when temperatures were warmer than normal. Even before the trees die, sap production lessens as trees sicken. In addition, if warming occurs more in the spring than in the winter (as some models project), buds may break early, making the sap bitter and leading to a shorter, less productive season.

Timber Industry

The timber industry is a vital component of the White Mountains region. Timber management occurs within the White Mountain National Forest, the largest management unit in the region, as well as in forests owned and managed by private individuals, large timber companies, and the state government. One EPA model of the effect of warming on the yield of timber species in New England showed increases in hardwoods, but decreases in softwoods (conifers). However, in models where forest species are allowed to migrate in response to changing climate, some timber species associated with this region currently may no longer be able to grow there in the future. The timber industry in New England has been remarkably flexible in the last few centuries since colonization by Europeans began. The industry thus may well be able to adapt to potential losses of spruce and fir and some northern hardwood species by potential increases in white pine or oak. However, during transition periods before establishment of new forest species, productivity could be greatly reduced. At this point we can only suggest that there are potential risks and benefits to the timber industry of this region and that further development of forest models is necessary before more accurate economic models can be developed.

These predictions, though based on current ecosystem and climate models and observable phenomena, can only serve as an illustration of potential outcomes of climate change; no one can predict with certainty whether the climatic and ecological response will undermine, destroy, or even benefit local communities and economies in the long run. Available evidence and informed judgment indicate, however, that climate change will dramatically reduce many of the values we currently associate with the White Mountains region, and that the people of the region face a very uncertain future if current trends continue.

The most effective means to safeguard the existing mosaic of industries, ecosystems, and communities in the White Mountains from the consequences of climate change is to slow and eventually reduce the emissions of greenhouse gases. Such a change cannot be effected by the people of New England alone. As with all other regional economies and ecosystems, their fate is tied to the wisdom of nations and people around the globe, specifically to international commitments to stem pollution. A better future for the White Mountains can be secured by local, national, and international cooperation to combat global climate change by reducing greenhouse gas emissions. Failure to do so may well have profound repercussions for all regions. This study offers a detailed picture of just one of those regions, New England's White Mountains, and an example of how global climate change can have tangible impacts at the local level.

PROLOGUE

There is a consensus among climate scientists that emissions of greenhouse gases due to fossil fuel use, deforestation and agriculture have probably caused and will continue to cause global climate change. Computer models of the climate are beginning to provide improved estimates of how much and how fast climate will change. Because several greenhouse gases survive in the atmosphere for many decades or even centuries after release, continued emissions near or above current rates would mean continued climate change and warming for centuries. Decision-making on emissions limitation would be improved by increased understanding of how climate changes could affect our natural resources, our health and our way of life.

To begin to approach this issue, we decided to look at a specific location, the White Mountains region of New England, and to illustrate a variety of potential outcomes of *not* acting to reduce emissions. We portray a range of visions based on what we know about the vulnerabilities of this system to climate change as it relates to different sectors and users of resources in this region. We have also looked at what values are at risk, both in terms of the economic cost to society and also in less quantifiable ways—for example, being able to return with our children to a favorite trout stream we visited as a child or smelling the maple syrup boiling in the air of a cold, early spring morning.

The issue is very complicated, especially when we look at how it will affect us personally, where we work and play. This is because we must examine not only how climate change could affect our forests, towns, and health directly—but how climate changes interacting with all the stresses that have already been imposed by natural and human causes—would affect these things. Another problem is assessing how our behavior might be altered in response to these changes.

This report presents a preliminary and largely qualitative attempt at portraying how integral climate is to the people who live in, visit and appreciate the White Mountains region. More research is needed to quantify the projected alterations. But it is clear that, according to our current understanding, the magnitude and rate of climate change projected to occur in the next hundred years—that is, within our children and grandchildren's lifetimes—is sufficient to substantially change the White Mountains region.

THE WHITE MOUNTAINS AND CLIMATE CHANGE

The White Mountains region of New England is located within the states of New Hampshire and Maine. It lies in the northern portion of New Hampshire within the counties of Grafton, Carroll and Coos in New Hampshire and Oxford county in Maine. It also includes the White Mountain National Forest in New Hampshire and Maine (770,000 acres). The White Mountain National Forest is a beautiful and popular recreation area. Heavily forested and mountainous, it includes wilderness, timber and wildlife management areas and the largest alpine area east of the Rocky Mountains and south of Canada. The Presidential Range of mountains, found within the borders of the National Forest, include 5 peaks above 5,000 ft (1524m) with Mt. Washington, at 6,288 ft (1916m), renowned for its spectacular views and equally extreme weather. Over 6 million people visit the National Forest each year for hiking, skiing, fishing, viewing fall foliage, or simply to enjoy the view, making it one of most visited in the country. Beyond the National Forest, the White Mountains region contains hundreds of towns that rely on tourism, as well as the timber industry, for their livelihood. The way of life for many residents of the region is to combine several different enterprises such as making maple syrup, farming, and working in the service and retail sectors catering to tourists. Residents and tourists alike are strongly attached to the rich natural landscape of forest, streams, and mountains.

This report will focus on the vulnerabilities and risks of climate change to the people and industries of the White Mountains region. While many uncertainties remain, there is a consensus among climate scientists that human activities, primarily the burning of fossil fuels, are changing the Earth's climate.[1] One predicted repercussion is an increase in global average temperature above 1990 levels of from 1.8 to 6.3°F (1.0 to 3.5°C) by the year 2100.[2] On a global scale, rain and snowfall amounts and timing are projected to change, as well as the frequency and severity of storms and the incidence of both drought and flooding.[3] Global climate change of this magnitude and speed is unprecedented in the last 10,000 years.[4]

In this report we will explore which sectors and users could be most affected by projected climate change. Our focus will be on what activities and industries are particularly vulnerable to changes in climate and what factors might contribute to that vulnerability. Vulnerability is contingent both on how dependent an activity or industry is on climate (e.g., a successful ski season is dependent on a cold winter) and how current stresses like pollution and development might increase its sensitivity to climate change. Our analysis of these vulnerabilities paints a preliminary picture of the risks to this region from climate change. This report contains scenarios, syntheses of existing model results, and suggestions as to how models could be improved—as well as some speculation based on our basic understanding of the systems involved. Our goal is to highlight where vulnerabilities exist, who would profit or lose from changes, and what these changes could mean to us as a society. Further research at the local and regional scales will clarify what the coming decades may be like in a world where climate is changing.

The following sections will discuss how climate change could affect a variety of activities and industries dependent on natural resources in the White Mountains. We explore the potentials for the disruption of the fall foliage season, declines in maple-syrup production, a shortened ski season, a decrease in trout habitat, and changes in the productivity of the timber industry. In addition, we explore how changes to the natural resources base of the White Mountains region could affect the lifestyle and economies of towns that are dependent on natural resources as their primary source of income.

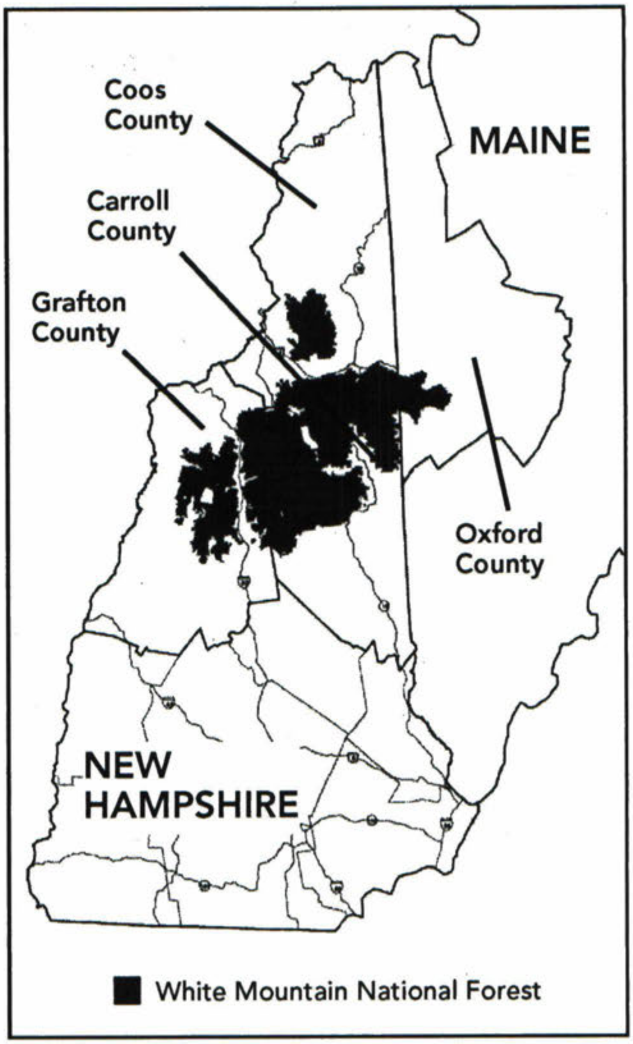
Understanding what sectors are vulnerable to climate change, the risks involved, and some of the underlying reasons why specific changes may come to pass will help us all make decisions on what actions we can take now to reduce these threats.

The Greenhouse Effect and Global Warming: How Will the Climate of the White Mountains Change?

The burning of fossil fuels such as oil, coal and natural gas, by cars, trucks, power plants and factories has substantially increased the amounts of greenhouse gases in the atmosphere relative to pre-industrial levels. Large-scale deforestation has also added significantly to greenhouse gas concentrations in the atmosphere. Today's atmospheric concentrations of CO_2 are 30 percent above the pre-industrial levels of 200 years ago[5]. Other greenhouse gases, including methane, nitrous oxide and tropospheric ozone, have also been increasing due to a variety of sources of emissions including agriculture, biomass burning, and landfills - in addition to fossil fuel use and deforestation.

Greenhouse gases are known to affect the climate. The earth and atmosphere absorb solar radiation and radiate heat back into space. Greenhouse gases, both natural and human-generated, trap a portion of this heat that would otherwise escape into space. This baseline "greenhouse effect" is essential to the earth's climate: without it the average temperature would be about 0°F (-18°C) instead of 60°F (16°C). However, human-generated greenhouse gases have augmented the concentrations of naturally occurring greenhouse gases to the extent that they are beginning to affect earth's climate. Current climate models predict that continued growth in concentrations of greenhouse gases will lead to increased surface temperatures (global warming) and changes in the amount, frequency, and timing of precipitation. The average global temperature has risen by 0.5 to 1°F (0.3 - 0.6°C) over the past 100, years and the eleven warmest years in the past 100 have occurred since 1980. Glaciers at mid-latitudes are receding. Intense rain and snow storms, fewer extremely low minimum temperatures, and other climate anomalies consistent with predictions of climate change have been observed with increasing frequency.[6]

Applying global climate model predictions to a specific location like the White Mountains region is a very difficult task. First of all, many geographic features such as lakes, mountains, and rivers—which are very important in determining climate and weather at local scales—are too small to be resolved by existing continent and region-scale climate models. Yet these features can make a big difference in exactly what climate or weather a particular location will experience. Weather refers to the changes in temperature and precipitation we experience on a day-to-day basis while climate refers to larger seasonal patterns. While it is hard to predict weather more than a few days in advance, climate can be modeled over long periods of time with a high-degree of accuracy. Models are being developed that will be able to project climate accurately for smaller regions. However, storm and drought frequency, and unseasonably cold or hot periods for particular locations are beyond the predictive capacity of existing models.[13] Unfortunately, it is just this scale of climate information that is most important in assessing affects on natural ecosystems. Currently, we can obtain the results of global



The White Mountains region lies within Grafton, Carroll and Coos counties in New Hampshire and Oxford county in Maine and includes the White Mountain National Forest in New Hampshire and Maine.

Box 1. Global climate models

General Circulation Models (GCMs) are the primary tools scientists use to predict the impact of increased CO_2 and other greenhouse gases on the global climate system. A variety of models have been put forward which provide a range of predicted climate scenarios over time. The models represent many complex processes concerning land, ocean and atmospheric dynamics, using both empirical relationships and physical laws. By varying the amounts of greenhouse gases in the model's representation of the atmosphere, future climate can be projected globally as well as regionally. However, GCMs are currently not reliable at scales much smaller than a continent. The highest numerical resolution of current models is 0.5° latitude by 0.5° longitude (roughly 1200 square miles). Even at this scale, the output should be taken as a representation of a trend and not as a precise prediction of climate at a particular date and location[7].

Since 1990, climate models have begun to incorporate the effects of sulfate aerosols. Atmospheric aerosols are small particles and very small droplets formed as by-products of the burning of fossil fuels in power plants, as well as through natural events such as volcanic eruptions[8]. Anthropogenic aerosols include sulfates, fossil fuel soot and organic aerosols from biomass burning.[9] These particles both absorb and reflect sunlight: sulfate aerosols in particular reflect sunlight and cool the earth, partially mitigating the impact of the greenhouse gases. Sulfate aerosols also lead to formation of cloud droplets that reflect sunlight. Volcanic eruptions, like that of Mount Pinatubo in 1991, release so much particulate matter into the atmosphere that they, too, can have a global cooling influence which has been modeled by GCM's. However, since human-generated sulfate aerosols also produce many negative impacts when they fall to the earth, such as acid rain, there has been strong support for abatement of their emissions. These aerosols have a much shorter life time in the atmosphere than CO_2 and affect the areas close to their source most strongly. Thus, future concentrations in the atmosphere will be closely tied with reductions at the source. Without their cooling influence, a greater warming due to greenhouse gases may be felt.

To predict future climates, modelers developed a series of scenarios of CO_2 emissions for the next century, based on estimates of population growth; rates of deforestation; what types of fuels are used (e.g., coal, natural gas, renewables); how much fossil fuel use increases, especially by developing nations; and how much sulfur emissions control is enacted and enforced. In one scenario, sulfate aerosol remains constant at current levels, while in others sulfate increases initially and then either decreases or continues to increase.[10] These scenarios allow us to estimate how global mean temperature would change in a variety of possible future worlds. For a range of scenarios and models, global mean temperature is projected to warm between 1.8 and 6.3°F (1.0 and 3.5°C) by the year 2100.[11] If it is assumed that sulfur emissions remain constant, the warming may be as high as 8°F (4.5°C).[12]

climate models that show temperature and precipitation projections for central North America as a whole and, for some models, New England. From this we can make some educated guesses as to what these forecasts might mean for the White Mountains region specifically. It should be borne in mind, however, that as regional and smaller scale models improve, climate predictions for specific locations will improve but may diverge from our current estimates.

In general, warming is predicted to increase with latitude, with the largest warming predicted to occur in late autumn and winter. Therefore New England and the White Mountains will generally experience higher than the globally averaged temperature increases.[14] In scenarios where CO_2 concentrations doubled and climate was allowed to reach equilibrium, which would occur several decades thereafter, New England's average annual temperatures were predicted to increase by 6 to 14°F (3 to 8°C).[15] (see Figure 1). In a business-as-usual scenario, concentrations of CO_2 are projected to double over pre-industrial concentrations by about the year 2060. Two "transient" climate model runs show the rate at which equilibrium is approached and project warming of about 3°F (2°C) for New England for the year 2060 (see Figure 1). One of these transient models, UKMO-TR, includes sulfate aerosols, which leads to less pronounced warming (see Box1). In general, transient models underestimate the eventual equilibrium warming associated with the concentration of greenhouse gases in the model at any particular time. This is because the atmosphere responds relatively slowly to additions of greenhouse gases, with a time lag of at least several decades. Even without further increases in greenhouse gas concentrations beyond what is projected for the year 2060, temperatures would continue to rise substantially over the next several decades. The higher end of the range of warming predictions for New England includes models that do not include sulfate aerosols and that have been allowed to equilibriate at twice the pre-industrial levels of carbon dioxide. These equilibrium models give an idea of the maximum warming that would be associated with greenhouse gas concentrations projected for the year 2060.

With increasing concentrations of greenhouse gases, models predict an increase in global mean precipitation.[16] When sulfate aerosols are included in the models, increases in precipitation are smaller. However, it is hard to predict how precipitation will change at the regional level. For central North America, there is a range in projections of precipitation, with different models predicting increases, decreases or similar amounts of precipitation.[17] In most cases, precipitation is expected to increase in the winter in central North America.[18]

Even if precipitation increases on an annual or seasonal basis, it is the soil moisture (how wet or dry the soil is at any particular time) that is crucial to the health and well-being of plants. In general, soil moisture depends on the total amount of pre-

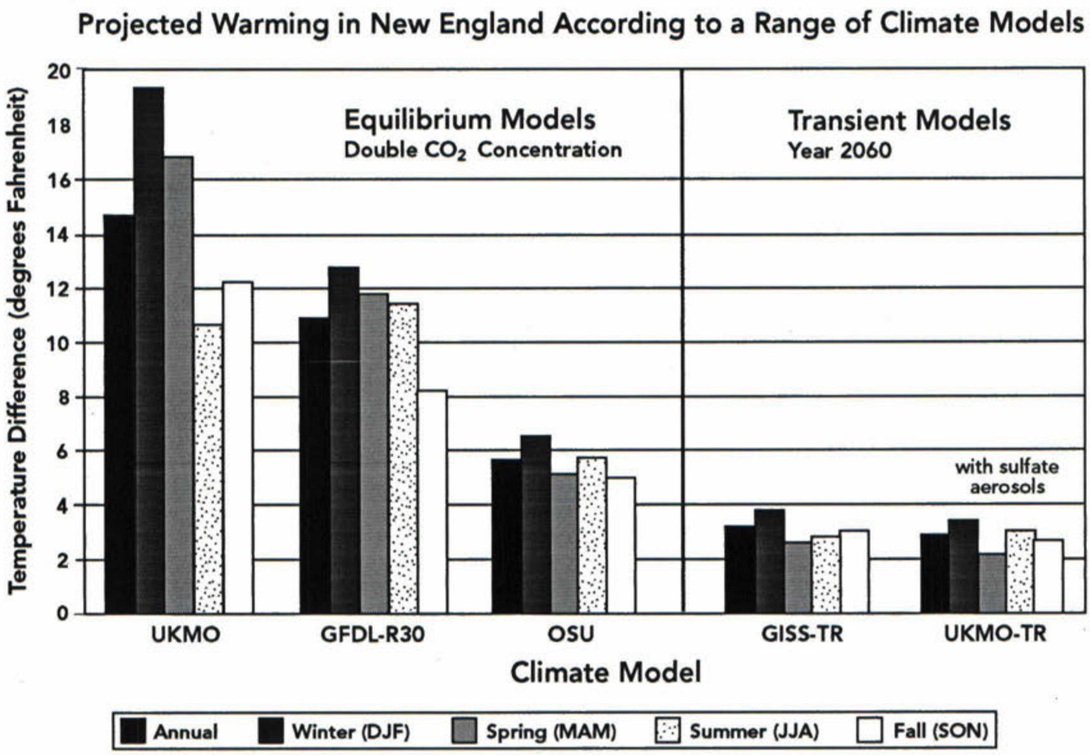


Figure 1. Increase in surface air temperature (in degrees Fahrenheit) for three climate models at double CO_2 concentrations compared to pre-industrial levels and for two transient models for the year 2060 as compared to 1990 temperatures. Equilibrium models shown are the UKMO (United Kingdome Metereological Office), GFDL-R30 Geophysical Fluid Dynamics Laboratory), and OSU (Oregon State University) models. Transient models include the GISS-TR (Goddard Institute of Space Studies transient model), and UKMO-TR (UKMO transient model). Only the UKMO-TR model includes sulfate aerosols.

Sources: UKMO, GFDL-R30, and OSU: Kittel, TGF, Rosenbloom TH, Painter TH, Schimel DS, and VEMAP Modeling Participants (1995) The VEMAP integrated database for modeling United States ecosystem/vegetation sensitivity to climate change. Journal of Biogeography 22(4-5) 857-862; VEMAP members (1995) Vegetation/ecosystem modeling and analysis project: Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. Global Biogeochemical Cycles 9(4) 407-437. UKMO-TR: Murphy, JM (1995) Transient response of the Hadley Centre coupled ocean-atmosphere model to increasing carbon dioxide. Part I: Control climate and flux adjustment. Journal of Climate 8: 36-56.; Murphy, JM and Mitchell, JFB (1995). Transient response of the Hadley Centre coupled ocean-atmosphere model to increasing carbon dioxide. Part II: Spatial and temporal structure of response. Journal of Climate 8: 57-80. GISS-TR: Russell, GL, Miller, JR and D Rind 1995. A coupled atmosphere-ocean model for transient climate change studies. Atmos.-Ocean 33: 683-730.

Box 2: Climate and Forests in the White Mountains: 14000 Years of Change

The forests of the White Mountains region that we visit today haven't always looked as they do now. Climate has a dramatic influence on which trees, shrubs, wildflowers and animals make up any forest community. In the White Mountains, temperatures in the past have been both considerably cooler and warmer than they are today, though records indicate that they have rarely if ever changed as rapidly as is projected to occur due to greenhouse gas warming in the coming years.[23] Natural disturbances such as fire and flooding have also shaped the character of forests in the White Mountains region.[24] For example, while fire is generally unimportant as a disturbance factor in the White Mountains region currently, during a warm, dry period approximately 7,000 to 9,000 years ago, fires became much more common.[25] These and other disturbances, such as pathogen and pest outbreaks and strong storms have significantly affected the species and character of the White Mountains forests.[26] Disturbances may increase in both frequency and severity at a global level with greenhouse-gas driven climate change.[27] Determining whether this increase in disturbance frequency will occur in the White Mountains with climate change is an important research task for the future. If disturbance frequency and severity do increase, it could mean dramatic changes in the forest ecosystems of this region.

Trees and forests have responded in dramatic ways to changing temperatures. Spruce is an example of a tree species in the White Mountains region that responds to temperature changes. Today, spruce in the White Mountains region grows only at relatively high elevations, between 2500 and 3300 feet (750 - 1,000m), where the microclimate (local climate) is cool and relatively moist.[28] Under these conditions, spruce have a significant competitive advantage over other species. However, when temperatures are too warm or too cold, other species may dominate. As the last glaciers began to recede from the White Mountains about 14,000 years ago, the region's mean annual temperatures were probably about 7.2 to 10.8°F (4 to 6°C) on average below today's.[29] Only sparse tundra was able to grow there. As temperatures warmed, the fossil pollen record shows that spruce began to colonize the area. By 6000 years ago, summer temperatures in North America were estimated to be 3.6 to 7.2°F (2 to 4° C) higher than today's, and were associated with the dramatic decline of spruce populations throughout the region.[30] Spruce maintained populations only in the cooler, higher elevations and farther north into Canada. As spruce populations declined, fir, larch, poplar, and paper birch populations moved into the newly opened areas. During a subsequent cooling trend beginning 5000 years ago, spruce populations were very successful at expanding their range again. Spruce were able to supplant northern hardwood at elevations between 2500 and 4000 ft (750-1220m).[31]

Forests have been fairly stable in the White Mountains for the last few thousands of years. At lower elevations, northern hardwoods - similar to those found today - began to appear around 7000 years ago. In general, forests indistinguishable from those seen today were established about 2000 years ago.[32]

cipitation, as well as its timing (seasonally), frequency, and intensity. Higher temperatures may cause the soil to be drier even if precipitation increases, because the added heat causes water to evaporate from soil and vegetation more quickly. In general, soil moisture is predicted to increase in the winter and to increase or decrease in the summer depending on location. When sulfate aerosols are included in the models, soil moisture is increased further. Frequency and intensity of rain in the summer can make a big difference in soil moisture. For example, the same average amount of monthly precipitation may fall as daily low-intensity drizzle or as twice monthly high-intensity downpours. Intense rains can lead to increases in erosion, mudslides and tree falls, which can cause dramatic changes to the landscape.[19] But, between infrequent heavy downpours, soils would dry much more than if light rain fell frequently. The end result would be much drier soil conditions leading to water stress for the trees and other plants. However, because of the dramatic topographic relief of the White Mountains region, soil moisture may not be as great a problem, since this area may still have ample rainfall, especially in the high-elevation areas, even if the region as a whole becomes drier.

On a global scale, climate change is often expressed or discussed in terms of average warming. But at a local scale, the climate and weather we experience is more variable, and how individual events will change is important to humans and ecosystems. Thus a general warming may lead to an increase in extremely high temperature days or heat waves, and an increase in consecutive dry days or droughts.[20] Increased precipitation may lead to a greater likelihood of heavy downpours. In fact, precipitation and temperature records made at hundreds of sites in the United States and a few other continental locations indicate that precipitation patterns have already changed substantially in the past hundred years, possibly as a result of greenhouse gas-driven climate change. For example, moderate precipitation events have decreased while extremely heavy precipitation events (greater than 2 inches per day) have increased.[21]

Greater warming is also predicted to occur at night than during the day. Most of the warming in the past century has occurred during the nighttime, leading to less differences between day and night temperatures. Minimum nighttime temperatures have risen almost three times as fast as the maximum daytime temperatures over much of the world. For the northeastern United States, annual diurnal temperature range (the difference between day and night temperatures) has decreased 1.8 to 3.6°F (1 to 2°C).[22] However, because nighttime warming is related to amounts of sulfate aerosols in the atmosphere, this differential may decrease over time if reductions in sulfur emissions occur (see Box 1).

Ecologists and other plant and animal scientists use projections of temperature and precipitation, as well as other climate variables, obtained as outputs from the GCM models, to create models of how natural and managed areas, and the plants and animals they support, could be affected by climate change. Since the latest GCM outputs have only recently been made available to the larger scientific community, many of the terrestrial models reported here are based on GCM runs that did not include the effects of sulfate and other aerosols and thus represent the higher range of projections.

ECOLOGICAL CONSEQUENCES FOR FORESTS OF THE WHITE MOUNTAINS REGION[33]

Most of the values and activities we associate with the White Mountains region are dependent on a healthy forest resource. Forest health has been characterized in a variety of ways but in this report we define it as a forest that is both robust and resilient to multiple natural disturbances such as fire, pest and pathogen outbreaks, and wind. It is further characterized as a forest ecosystem in which the multiple uses of timber production, water resources and other ecosystem services, as well as recreational and ecological values are maintained in a sustainable fashion.

From maple sugaring in the spring to hiking in the summer to viewing foliage in the fall to skiing in the winter, the economic and recreational calendar of the White Mountains is built around forests. Healthy forests are also the backbone of the timber industry, an important economic resource for this region. Climate change of the magnitude predicted by current climate models has the potential to both alter the species of trees and cause decline and widespread mortality in the forests of the White Mountains. However, it is difficult to predict with accuracy the fate of these forests; some models show increased productivity due to the longer growing season that would occur with warmer average temperatures. To address these issues, we present first, a synthesis of current model predictions—both in terms of species shift and productivity—and second, suggestions as to where forests are vulnerable to climate change in ways that have not as yet been adequately addressed by models. Since most ecological models are not yet accurate beyond a regional scale, we will look at the results of models applied to the forests of the northeastern United States as a whole and apply the relevant parts of their results to the White Mountains region.

Changes in Forest Species and Forest Types Predicted by Current Ecological Models

In general, ecological models predict that warmer temperatures would move optimal conditions for the growth of northern hardwood forest species northwards—including those we generally associate with the brilliant displays of fall colors in the White Mountains region—by at least 100 to 300 miles by the end of the next century.[34] Northern hardwood forest species may also move upward in elevation to maintain current climate conditions. However, while tree line will probably increase in elevation with warming, soils at higher elevations are often thin and acidic, and they could prove inhospitable, especially in the short term. High winds, common to high-elevation sites, may also limit upward expansion of the hardwoods. Forests

Box 3. Exploring the potential impacts of climate change and detecting its "fingerprint" in the ecosystems of the White Mountains: The importance of long-term data

Because climate change is projected to occur over the course of decades, detection of its "fingerprint" on the ecosystems of the White Mountains as early as possible will be essential both to improve our understanding of the impacts of climate change on the region and to plan and cope with future alterations. But the large natural variability in the weather, disturbance regimes, stream flows and other patterns and processes that occur in the White Mountains may make it difficult to recognize climate-induced changes if and/or when they occur. Detecting change will be dependent on understanding the forest and other ecosystems well enough to separate natural variability from the effects of a changing climate. To do this, scientists will need to use data that have been collected over a period of time long enough to be able to characterize normal variation (see Figure 2).

Reliable "long-term" ecological data, extending over a period of decades, exists for only a few areas in the world. Luckily, one of those areas is the White Mountains. The Hubbard Brook Experimental Forest, in West Thornton, New Hampshire in the heart of the White Mountains has been a focus of long-term research, research that pioneered the integration of ecosystem-level experiments and observations on the scale of small watersheds.[35] Research at Hubbard Brook is coordinated by the USDA Forest Service and represents a cooperative effort among researchers from numerous universities, research institutions and government agencies. As a result of the ongoing work of over a hundred scientists over the period of the last four decades, there exists a large body of continuously measured data on weather, forest growth and species composition, hydrology, precipitation, lake and stream chemistry, lake and stream biology and biogeochemistry for the Hubbard Brook Experimental Forest.[36] Though most of the research has not focused explicitly on climate change, the data amassed provide a detailed understanding of how chemical nutrients, precipitation, stream water, pollutants, and vegetation interact in this northern hardwood forest, its streams, and a naturally nutrient- poor, low-productivity (oligotrophic) lake found within the forest.[37] The data generated by this effort are complemented by 60 years of forest inventory data available from the Bartlett Experimental Forest, Bartlett, New Hampshire, also located within the White Mountains.[38]

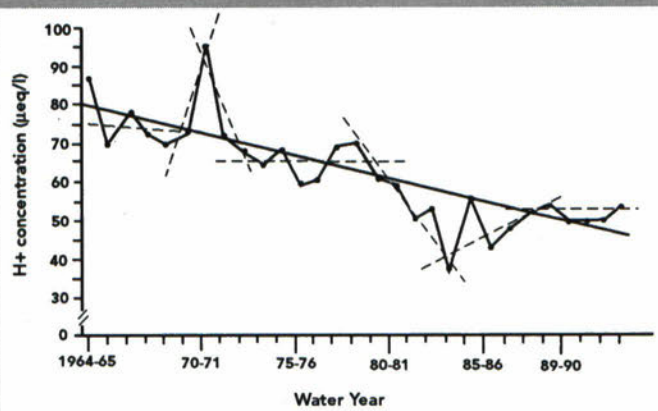


Figure 2. An example of natural variability in long-term ecological data sets. Trends are apparent with 30 years of record that would be difficult to distinguish if only 3 or 5 years had been measured. The graph depicts the annual, volume-weighted concentration (µeq/liter) of hydrogen ion (a measure of acidity) for a portion of the Hubbard Brook Experimental Forest from 1964-1965 to 1992-1993. From Likens, GE and Bormann, FH, (1995). Biogeochemistry of a Forested Ecosystem, Second Edition, Springer-Verlag New York. 159pp.

Beyond simply detecting change due to global warming, these long-term data could also be used to generate detailed projections of the potential impacts of climate change on the forests of the White Mountains. Projections could go beyond current models that focus on the effects of temperature and precipitation changes alone to include the multiple, interactive effects that actually define how ecosystems function and respond. For example, changes in precipitation patterns could lead to alterations in stream flow and chemistry that could affect forest productivity. In one scenario, acid precipitation, of the magnitude currently occurring, combined with more intense storm events could decrease soil available calcium, thereby increasing the amount of calcium leaving the forest in stream water and ultimately lowering forest productivity. Without a detailed, long-term record of forest productivity, stream chemistry, and acidic deposition, this type of interaction would be impossible to identify. Other examples of interactive effects that could be studied using these long-term data sets include examining the movement of nitrogen in soils as a result of greater warming at night relative to the day, the impacts of increased loss of water through soils and foliage due to warmer temperatures (evapotranspiration) on tree growth, and the relationship between climate and disturbance patterns like increased fire or pest and pathogen outbreaks and their affect on forest productivity.

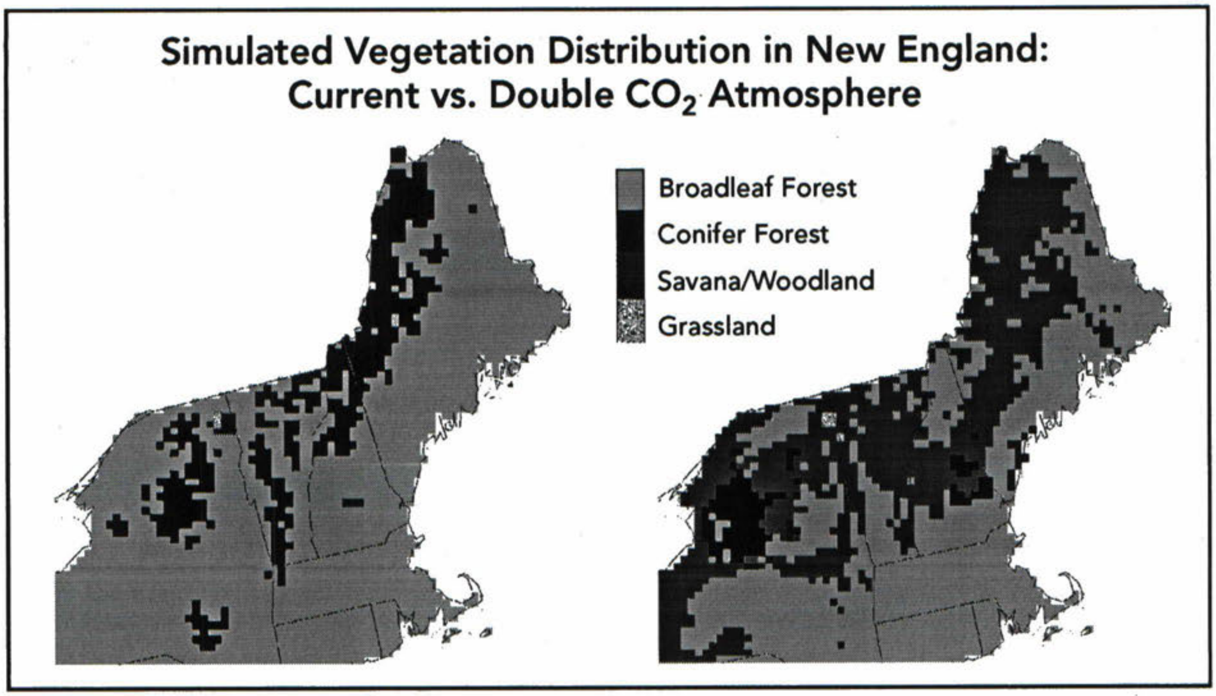


Figure 3. Current (left) and future (right) potential vegetation for New England using the MAPSS vegetation model with climate simulated by the GFDL-R30 equilibruim climate model, which projects temperature and precipitation changes for a double CO_2 atmosphere that are approximately the middle-of-the-range of equilibrium climate models (see Figure 1). As can be seen, conifer forests largely disappear from the region and much of the northern hardwood forest is replaced by savanna/woodland.

Source: Neilson, RP (1995). A model for predicting continental-scale vegetation distribution and water balance. Ecological Applications 5: 362-385; VEMAP Members. 1995. Vegetation/ecosystem modeling and analysis project: Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. Global Biogeochemical Cycles 9:407-437.

that currently grow at higher altitudes (2500 to 4800 ft, 762 to 1463m), like the red spruce and balsam fir communities, could have little room to migrate upward as they approach the tree line. As optimal conditions for growth of forest species change due to changing climate, forests would be at greater risk to disturbances like fires, and pest and pathogen outbreaks, as well as to unusual weather such as mid-winter thaws or winters with little snow cover. In general, this could lead to decreased health and increased mortality. Given sufficient warming, these spruce forests could be lost or reduced significantly in size. There are indications that climate-related mortality has already been occurring in the spruce/fir community (see Box 4).

One model (MAPSS) estimated changes in forest types with a climate change scenario of doubled CO_2 concentrations including direct CO_2 fertilization in northeastern US forests as a whole (Figure 3).[39] The results included widespread tree mortality, decreases in vegetation density of 25-75 percent, extensive wildfires, and a lag in establishment of new forests of several decades.[40] Forests that were constrained to cool climates, such as northeastern hardwoods and high-altitude forests were lost or reduced significantly in size.

Changes in Forest Productivity Predicted by Current Ecological Models

Warmer temperatures, combined with higher CO_2 concentrations in the atmosphere, could cause forests to be more productive, accumulating more carbon as biomass. One model of forest productivity that covers the northeastern United States (PnET-II)[52], used a scenario of increased temperature (10.8°F (6°C)) and decreased precipitation (15%), which resulted in an increase in wood production in all stands due to the increased length of the growing season and warmer temperatures. In the model, increased CO_2 allowed the trees to use water much more efficiently, thus overcoming possible problems with drought.

Another forest ecosystem model, Terrestrial Ecosystem Model (TEM)[53] also found that climate

Box 4. Spruce decline

Many of the high-elevation red spruce forests of eastern North America have experienced rapid population declines in the last 30 years.[41] Tree ring widths, a measure of tree growth, began to decrease simultaneously through the Catskills, Adirondacks, and the Green and White Mountains after about 1960, regardless of disturbance history or tree age.[42] The mortality of red spruce increased with increasing elevation.[43] The increased mortality was probably not primarily due to senescence, stand age, drought or pathogens.[44]

Spruce decline has been related to a complex combination of factors, which include acid precipitation, winter injury, ozone injury and climate change.[45] Long-term data collected at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire suggests that acid rain may be responsible for the loss of large amounts of calcium and magnesium, nutrients essential for plant growth, from the soil.[46] Loss of calcium may also lead to the release of aluminum in soils, which is toxic to tree roots in high enough concentrations.[47] Acid precipitation has been related to direct foliar damage by dissolving the waxes that protect needles (cuticles) and by causing red-brown needle discoloration.[48]

Climate-related factors that may contribute to increased spruce mortality and that may increase with projected climate change, include rapid thawing events during the winter followed by hard frost, which could increase the frequency and severity of winter injury.[49]

Long-term records also point to a connection between climate and spruce mortality. When records of spruce distribution are examined, there appears to be a decline in spruce abundance at middle-elevation sites from 1800 to the present.[50] The major driving force of the decline appears to be a warming trend in both mean annual and mean summer temperatures. Climate records from Hanover, NH show a 3°F (1.7°C) increase in yearly temperatures and a 4°F (2.2°C) increase in summer temperatures over the past 150 years.[51]

change consistent with doubled CO_2 led to increased productivity for the northeastern forests. In this model, the boreal forest type (spruce/fir forests) showed particularly dramatic increases. This may be because these forests are generally limited by nitrogen availability. The warmer temperatures led to more decay of dead needles and wood on the forest floor, releasing more nitrogen - an essential nutrient for plant and tree growth which is usually limited in supply in these forest types. However, atmospheric nitrogen deposition due to pollution in the northeastern United States is currently 10 to 20 times above historic background levels. These high nitrogen inputs could eventually saturate the nitrogen retention capacity of the forest, lessening growth enhancement over time.[54]

The effect of increased carbon dioxide on forest productivity

Carbon dioxide makes up the largest fraction of the human-generated greenhouse gases which cause global warming. Carbon dioxide also has a crucial biological role in plants; it is the source of carbon that plants use to grow and make leaves, wood, and roots. Plants may experience both warmer temperatures and significantly higher concentrations of CO_2 in the coming century. Elevated CO_2 is thought to both increase productivity and allow plants to use water and nitrogen more efficiently, which could also result in greater resistance to drought. While individual plants grown under controlled conditions have been shown to grow more quickly under higher concentrations of CO_2,[55] how natural forests could react is much less well known.[56] There are several scientific reasons for this:

- Studies performed on young plants or seedlings that showed large enhancements of growth may not apply to mature forest trees.[57]
- Since different species or genotypes within species are known to react differently to increased CO_2, competition may lead to shifts in species composition that are hard to predict.[58]
- Higher temperatures could depress some of the increased efficiency of water use by the plant.[59]
- Some species may stop responding to higher than double CO_2 concentrations due to saturation,[60] yet greenhouse gas levels could continue to increase well beyond this level.
- Over time, species may adapt to increased CO_2 levels and stop their increased growth response.[61]

- Early growth increases may disappear as other essential plant nutrients (e.g., nitrogen) or water become limiting. However, this effect may be mitigated in some areas like the northeastern United States where nitrogen in being added to soils from air-borne pollution sources.

Despite these difficulties inherent in applying the CO_2 fertilization effect to natural forests given our current state of knowledge, most forest productivity models (such as TEM and PnET-II described above) apply the CO_2 fertilization effect by increasing growth rate of all modeled forest species uniformly. This has a profound impact on the final results, in some cases completely mitigating any negative effects of climate change, resulting in large increases in predicted productivity for northeastern US forests. These high-productivity estimates should be viewed with caution until a fuller understanding of the impact of higher CO_2 concentrations on natural forests is gained from further research.

Transient vs. equilibrium models

Most ecosystem models with results available for New England, including the three discussed above (PnET-II, TEM, and MAPSS),[62] are so-called equilibrium models. This means that the model looks at the difference between climate as it exists today and conditions under climate at a set point in the future. In these models, scenarios are built of future climate, commonly with CO_2 at double the pre-industrial levels though others exist using higher concentrations. The models assume that an equilibrium has been reached in terms of both vegetation response and climate change. Even if CO_2 concentrations stop increasing after they reach double the pre-industrial levels—an unlikely scenario—which is predicted to occur by around the year 2060, it would be many decades before climate reached an equilibrium, and perhaps centuries before vegetation would equilibrate as well. Equilibrium modeling can give us an idea of what the forest or ecosystem might look like under various ultimate scenarios - in a world with a stable but warmer and possibly drier climate. However this type of model misses a lot of the complexity of how forests respond to rapidly *changing* climate.

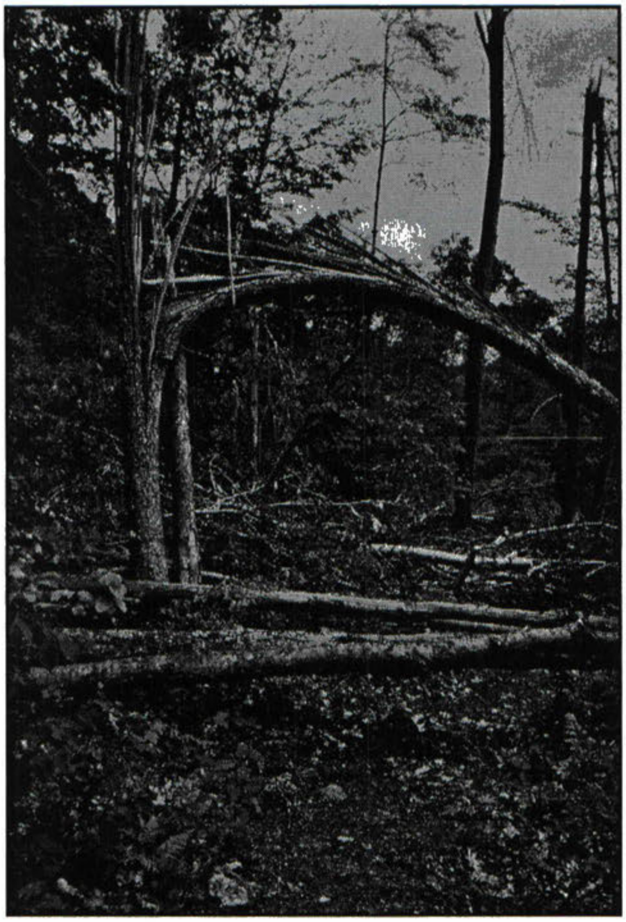
One factor that is predicted to increase as climate changes is disturbances.[63] While disturbances, such as pest and pathogen outbreaks, flooding, and wind damage, have always been an important part of the dynamic landscapes of the White Mountains region, climate change may increase their frequency and severity. Disturbances can kill large numbers of trees and forests. When forests come back, their species composition, the types of trees that will grow there, is often different than before the disturbance. For example, a sudden drop in hemlock populations in the White Mountains and other sites in eastern US and Canada 4,800 years ago has been attributed to a pathogen outbreak similar to ones that have caused the modern-day declines of chestnut and elm. Hemlock persisted at low levels but only returned to its pre-decline abundance after about 2,000 years.[64] An equilibrium model would miss this type of phenomenon because it looks only at current and future states, not at how the change occurred. Transient modeling, which models both climate changes and forest responses at yearly or even monthly intervals, at a fine enough scale to capture these types of occurrences is extremely difficult but is being actively pursued. One class of models, individual-tree-based "gap" models holds perhaps the best promise for exploration of transient forest responses to climate change.[65]

Vulnerability of White Mountain Forests to Extreme or Unusual Weather, Pollution and Disturbances: Going beyond existing models

All models are by necessity simplifications of reality; we are not yet able to build in all factors that could affect forests. Three important factors that have not been adequately incorporated into models (though there is on-going work to include them), but that are predicted to increase with climate change, are the impact of extreme and unusual weather events, pollution and disturbances on forests.

Extreme or unusual weather

Extreme events or unusual weather patterns—like periods of winter thaw followed by intense cold; spring and summer drought; and summer heat stress—can have profound impacts on the forests of the White Mountains region. These types of extreme events or unusual weather patterns have been tied to diebacks and declines in several northern hardwood species in New England in the last hundred years.[66] Because these forest types occur within the White Mountains region, if certain types



An example of physical damage to trees that can accompany high winds during storms. (photography: Marny Ashburn/AMC).

of extreme weather events and unusual weather patterns increase as is predicted by climate models, the forests of the White Mountains region may be vulnerable to widespread mortality from forest decline.

In the past, episodes of rapid warming have been closely tied with the onset of widespread crown dieback and decline in eastern Canada for several northern hardwood tree species: ash in the mid 1920s, birch from 1935-1955, and sugar maple from the 1980s to the present.[67] These dieback episodes corresponded to widespread increases in annual mean temperatures, increases in certain types of extreme events, and summer droughts.[68]

More recently, episodes of sugar maple declines in southeastern Quebec in the 1980s have been tied to a combination of winters with periods of loss of snow cover, followed by deep freezes, and in turn followed by summer drought. A variety of physiological mechanisms may be responsible for these dieback episodes. Roots are more sensitive than other tree organs to temperature extremes; without snowcover, any hard frost can lead to increased root mortality. In northern hardwoods, persistent winter snowcover typically provides protection to the fine roots from extreme cold. This may help to explain the observation that the southern limit of northern hardwoods corresponds more or less to the incidence of persistent winter snow accumulation.[69] Fine roots, like those of the shallow-rooted sugar maple, are most susceptible when close to the surface. Trees whose root systems are already limited (e.g., by drought or shallow soils) are also highly susceptible to dieback.

Unusual thaws can also cause buds to break their winter dormancy prematurely and open long before spring. The buds can subsequently be killed by a return to freezing temperatures.[70] A tree already weakened from loss of fine roots due to thaw-freeze events in winter can be further stressed by summer droughts. Drought causes a depletion of sugar reserves due to lower photosynthetic performance.

Recent studies have shown that mature forest age is a pre-condition for the climate to incite dieback by freezing injuries as described above. Large dieback episodes correspond especially well with the point at which ash, birch, maple and red spruce stands attain maturity.[71] This means that a large portion of the NE forests could be threatened by climate-induced injury because the NE forests in general are aging and a sizable area is at or near maturity.

There are some indications that the duration of winter snow-cover has already been decreasing in the northeastern United States since the mid 1970's. For example, records from Lennoxville, in southern Quebec, have shown a marked increase in the number of days during the winter without snowpack in the last 20 years from 35 to 95 days (taken as a 5 year average).[72] In general, northern hemisphere snow-cover has been consistently below the 21-year average (1974-1994) since 1988.[73]

Pollution

Pollution can weaken trees, making them more susceptible to climate changes due to greenhouse-gas-driven warming. Pollution, including acid deposition, nitrogen deposition, and high ozone concentrations already affects forests in the Northeast, and certain pollutant emissions, particularly those that generate ozone, may increase in the coming century.[74] Once weakened, the trees often succumb to pests and pathogens they might otherwise easily combat when healthy.[75]

When acidic mist or rain falls, nutrients can be leached directly out of the leaves. Acid rain falling on soils can leach important nutrients like calcium out of the ground lowering its availability to the trees,[76] which can lead to the release of toxic elements including aluminum that can kill tree roots. Trees that lack important nutrients are weakened, becoming more susceptible to attack by insects and pathogens, and more vulnerable to certain types of extreme events associated with climate change, like droughts and thaw/freeze events in winter.[77]

Disturbance

Disturbances including fire, wind, flooding, and pest and pathogen outbreaks are common occurrences in forests and, most of the time, forests can recover and grow well after them. In fact, forest health is probably dependent on regular natural disturbances. However, more severe disturbances caused by human activities and climate change may be much more difficult to recover from. Climate change could be directly responsible for increased disturbance; for example, warmer temperatures could increase the range of pests into new areas. Climate change could also be indirectly responsible; dry hot weather and higher numbers of dead or dying trees would make conditions better suited for wildfire.[78] In addition, natural disturbance—or disturbance caused by humans but unrelated to climate change—could make the impact of climate change more severe. For example, large portions of the White Mountains region were cleared for agriculture in the 19th century, leading to a young, fragmented forest. By its peak, in 1850-1880, at least two-thirds of Grafton County was cleared of forests to allow for agricultural activities.[79] Areas that have been fragmented historically may create barriers to migration of species necessitated by changing climate.[80]

Fire

The White Mountains region, as well as most of northern New England, rarely experience fires today. Fires are more common in southern New England in the drier pine-oak forest types.[81] Climate change could create conditions conducive for fires further north. Drier soil and fuel conditions, an increase in the occurrence of heat waves, and an increase in fuel loading from increased morbidity and mortality would create conditions highly conducive to wildfires. In addition to direct physical damage, fires can change species distribution and productivity and will tend to favor early-successional, fast growing species.[82]

Wind

There is no consensus yet as to whether winds will intensify or weaken in the future.[83] However, if storm-driven wind does increase, it could lead to increased physical damage. New England forests are subject to three major classes of destructive windstorms: tropical cyclone (hurricanes), extratropical cyclones, and more-localized intense winds associated with stormfronts and thunderstorms.[84] Northern New Hampshire and Vermont have been struck by severe hurricanes only twice, in 1815 and 1938 over the period 1492 to 1976. As a result of the 1938 hurricane, nearly 3 billion board feet of timber were blown down affecting 243,000 ha of forest land in Connecticut, Rhode Island, Massachusetts, and Vermont. Weakened trees or local wind-prone sites were most affected. There is no consensus yet on whether hurricanes will increase or decrease in intensity or frequency due to climate change. However, increased numbers of localized intense storms could increase windthrow, especially in places where trees are exposed due to clearing of neighboring forest.

Flooding

Flooding may increase in frequency and intensity as a result of climate change. This is thought to occur in general because warming would release greater amounts of water into the atmosphere's hydrological system at a global level.[85] At a local level, this could result in an increase in frequency of intense downpours[86] leading to rapid melting in the spring and/or an increase in rain-on-snow events. Warmer-than-current springs could also intensify spring snowmelt. Increased flooding in the White Mountains region could lead to increased rock and mud slides, leading to physical damage in the forest, riparian (river-side) zones, and property. Runoff can also disrupt municipal water treatment and delivery systems, wash out bridges, highways and other human infrastructure, and inundate croplands. An example of a particularly intense rainfall event occurred in October 1996 when record rainfalls flooded homes, broke off water supplies in Portland, Maine and Exeter, New Hampshire and washed out highways and bridges throughout New England.[87]

Pest and Pathogen Outbreaks

Warming in winter may allow destructive insects and pathogenic fungi to survive at higher latitudes than at present, enabling subtropical or warm-temperature pests and pathogens to invade vegetation in areas from which they are now excluded.[88] For example, one of the factors that may currently be slowing the northward spread of hemlock wooly adelgid may be the length and severity of winter.[89] Hemlock wooly adelgid attack is currently causing catastrophic loss of hemlocks in southern New England. Hemlock is a key species for deer during the winter in this region. Drought stress, which may also increase with climate change, may also lead to increased pest outbreaks. For example, in New England, periodic epidemics of spruce budworm which result in the killing of mature balsam fir and spruce stands over large areas, are related to warm, dry summers and the conditions associated with drought.[90]

CLIMATE CHANGE AND THE TOURISM AND RECREATION INDUSTRIES

The White Mountains region has a large investment in maintaining the natural resources that attract so many people to take part in their varied tourist and recreational opportunities. Climate change has the potential to affect many of the key natural resources that draw visitors to the area throughout the year. The natural beauty and recreational attractions have also made the area one of the most popular locations in the country for vacation homes. The quality of fall foliage viewing, skiing and snowmobiling in the winter, and fishing and hiking in the summer are all vulnerable to the rapid climate changes predicted to occur in the coming years.

The tourism and recreation industries are critical to state economies of this region. Much of the White Mountains region is found in the state of New Hampshire. The travel and tourism sector in New Hampshire resulted in $2.5 billion in direct spending and $1.5 billion in indirect spending for 1994, which represented 9.5% of the gross state product.[91] The White Mountains region accounted for 18% of that spending.[92] In the New England area in 1991, over 58 percent of residents participated in some form of wildlife-associated recreational activity and spent approximately $2.5 billion to do so.[93] Visitors to New Hampshire's ski areas spent $139 million during the 1992-1993 ski season. This direct spending led to over $178 million in secondary sales, including hotel and restaurant purchases.[94] The three northern New England States (Maine, New Hampshire, and Vermont) have consistently had the highest percentage of vacation homes in the United States since the census first started keeping track of this in 1940.[95] In 1990, for example, 11% of New Hampshire housing were vacation homes. If climate change alters the primary characteristics that draw people to these activities, then subsequent changes in participation rates can also be expected. Changes in participation will have direct effects on the region's economy.

The fall foliage displays

Every autumn in the White Mountains region, deciduous trees prepare for winter. During that process their leaves turn a brilliant mixture of reds, purples, oranges, yellows and browns. This fall foliage display is a popular tourist attraction bringing in so-called "leaf-peepers" from all over the world. The weekends during the fall foliage season, running between mid-September to mid-October, are often the busiest of the year for the tourism industry.[96] The fall foliage season is vulnerable to climate change because the quality of the display and colors are dependent on which tree species are present as well as individual tree health - both of which may be affected by changes in climate.

Leaves change color when temperatures grow cooler and days shorter in the fall. First, the connection which allows the leaf to exchange sugars, water, and nutrients with the rest of the tree is blocked, trapping any remaining sugars within the leaf. Next, the green pigment, chlorophyll, which allowed the leaf to produce sugars during the summer, begins to deteriorate and lose color. Other pigments that were always present in the leaf, but masked due to the abundance of the green chlorophyll, begin to show through. These pigments are typically yellow, red, or orange (carotenoids, anthocyanin and xanthophylls). Maples often display a particularly brilliant red hue due to the large amounts of sugars that are trapped or produced in

A typical New England scene, the change of seasons, may be threatened by global warming. (photography: Paul O. Boisvert).

their leaves.[97]

Many factors, including soil type, site quality, soil moisture availability, and genetic characteristics, can interact with climate to produce varying qualities of color display. Because of this complexity, predicting a good foliage display is often an educated guess at best. However, certain climatic factors are known to contribute to the quality of the color display. For example, summer droughts tend to disrupt fall color displays in a number of ways. Droughts can cause leaves to dry, shrivel, and fall to the ground before producing any significant color.[98] Warmer temperatures will increase water loss from plants and soils. If rains do not increase enough to offset this, drought conditions will become more common. Even in a mild drought, fall colors can become uncoordinated when the leaves of drought-intolerant trees, like ash and birch, change color and fall earlier than the leaves of more drought tolerant trees like red maple and oaks.[99] However, higher CO_2 concentrations may lead to greater production of sugars in the spring and early summer, leading to some trees producing more intense colors when their leaves do fall.

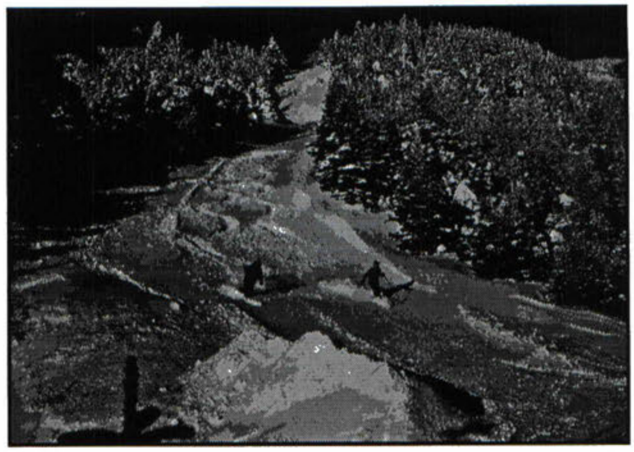
Climate models predict that warm temperatures will continue longer into the fall than currently. This might suggest that foliage will simply change color later in the season, for example in November instead of October. But leaf fall, and therefore color change, is triggered by both temperature and day length. Some trees are more directly influenced by day length than others.[100] This, too, would lead to an uncoordinated display where those trees more influenced by day length would change color and drop their leaves earlier than those trees more influenced by temperature. Because of warmer nighttime temperatures, respiration, the energy used for the tree's growth and maintenance, could increase, leading to greater loss of sugars from the tree. This may dampen the colors of some species, especially those like maples that require large amounts of sugars to produce red anthocyanins. Increased rain in the fall and cloudy warm weather would also reduce color. Clouds would lead to less production of sugars and warm weather would increase losses of sugars due to respiration. The best colors occur when falls are dry but not droughty.

Finally, climate change may lead to decreased quality of fall foliage as those trees currently found south of this region displace those currently located in the White Mountains region—as is predicted by some models of potential vegetation change as a function of temperature (for example, see Figure 3).[101] If current northern hardwood species such as sugar maple, spruce, and fir populations decline while oak and other trees currently found in the south increase, then the unique combinations of brilliant red maples, yellow birches, and touches of dark green conifers may be replaced by the more uniform browns of the oaks, currently found south of the region (see Page 10). In addition, in the process of species shift, individual trees will sicken and die resulting in fewer robust trees that can produce thick displays of brilliant colors.

Ski industry

The ski industry in New Hampshire plays a significant role in the state's economy and especially in the economy of the White Mountains region. The length of the ski season and therefore the success of the ski industry, is inherently tied to weather. Any significant change in climate will have a direct impact on the ski areas and the economy of the region (see Box 5).

Any significant warming in the region will most likely cause the ski season to begin later and end earlier though expanded snowmaking could mitigate this somewhat. Currently, the ski season generally lasts from December to April. Larger resorts with snowmaking capability open one to two weeks prior to Thanksgiving and close in late April. To estimate the potential impact of climate change on the winter ski season, we looked at temperature records from Pinkham Notch, New Hampshire, located within the White Mountains region near Mt. Washington. We defined the potential number of winter season days as those days with maximum temperatures below 32°F (0°C) between November 1 and April 30. Between 1956 and 1995, there was an average of 165 winter season days (Figure 4). Using two warming scenarios, one of plus 3.6°F (2°C), the other of plus 7.2°F (4°C), the season length decreased to 149 and 130 days respectively. This represents a loss of about 10 and 20 percent of the total season length. While most of the warming would serve to shorten the length of the season, some would occur as mid-season thaws, which would necessitate additional snowmaking to rebuild the snow base. Some models predict that



The ski season in New Hampshire may be considerably shortened due to warming temperatures as a result of climate change. (photography: Paul O. Boisvert).

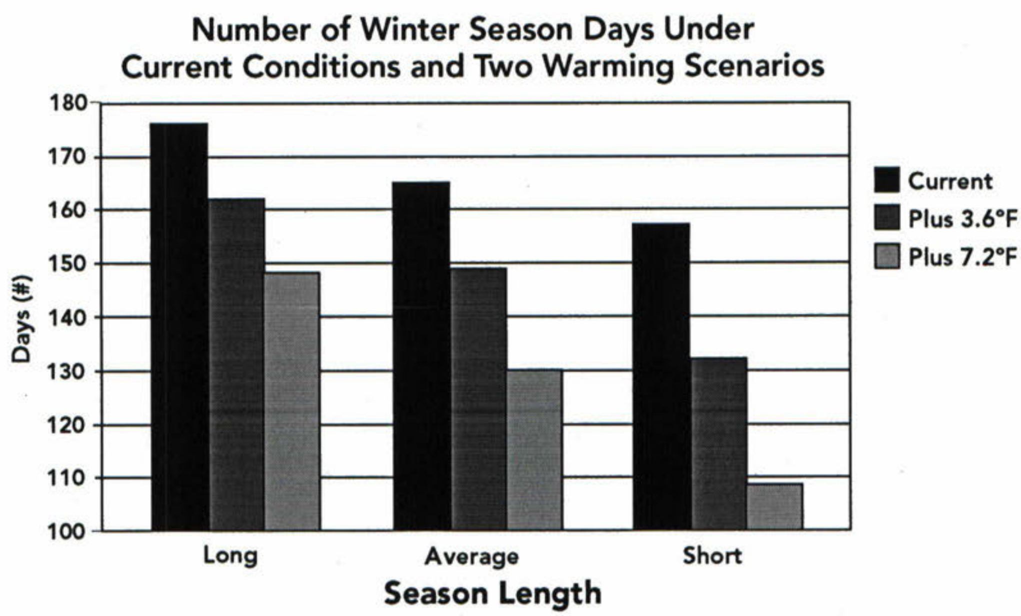


Figure 4. Number of winter season days in Pinkham Notch, New Hampshire under current climate conditions and two warming scenarios: plus 3.6°F (2°C) and plus 7.3°F (4° C). Winter season days are defined as those days whose maximum temperature is below 32°F (0°C) between November 1 and April 30 of a given year. The range of winter season lengths are represented by long, average and short length seasons between the years 1956 and 1995.

Source: Weather data obtained from the Northeast Regional Climate Center, Cornell University, Ithaca, NY.

Box 5. The Economic Importance of the Ski Industry to New Hampshire

New Hampshire has 28 alpine and nordic ski areas of which 11 are located in the White Mountains region. Since the 1983-84 ski season, skier visits to New Hampshire have risen and fallen, with peaks occurring during the 1985-86 ski season, during the 1988-89 season, and during the 1992-93 season. The greatest number of visits occurred during the 1992-93 season with 2.1 million skier visits. The low during this period occurred during the 1984-85 season, which had less than 1.5 million skier visits. Since the 1994-95 season, skier visits have again been on the rise. Direct spending by ski area visitors in New Hampshire during the 1995-96 ski season totaled nearly $190 million. This represented 8.6 percent of the state-wide total of $2.8 billion for direct visitor spending (for the period July 1995-June 1996) and 55 percent in the four northern and western travel regions (for the five month ski season).[102] Ski areas have been offering an increasing variety of summertime activities such as alpine slides, festivals, and horseback riding. As a result, off-season visits have been increasing by an annual average of 3.3 percent over the last decade (FN Compounded 1985-1995). However, revenue generated during the off-season is considerably lower than during the ski season; the total spent in the summer of 1995 was $53 million.[103]

The ski industry also generated an estimated $319 million in secondary sales between July 1995 and June 1996. State and local governments received $18 million in taxes and fees from direct ski area and visitor spending in the form of property, business, profit, room, meal and other taxes. An additional $48 million was received from taxes associated with secondary spending. Alpine and nordic ski areas employed 4,586 full- and part-time people during the ski season. An additional 12,551 people were employed in other establishments where skiers made direct purchases, or at establishments supported by secondary sales, from skier spending during the ski season. The annual payroll from these jobs totalled $185 million. These figures represented 4.2 percent of all jobs and 2.1 percent of household payroll for the four travel regions.[104]

precipitation will increase in the winter, while others predict similar or slight decreases.[105] If precipitation falls as snow, this could reduce the need for snowmaking. However, if precipitation falls as rain due to warming temperatures, this could lead to rain-on-snow events which could cause a deterioration of snow conditions required for skiing. Additional snowmaking would be necessary to recoup losses.

Ski areas already invest heavily in snowmaking equipment to extend the ski season. The two main factors influencing snowmaking are temperature and water availability, both of which may be affected by climate change. Attitash Mountain in New Hampshire spends $750,000 per year on snowmaking, which represents 20 percent of their operating cost. Temperatures should be less than 28°F (-2.2°C) for successful snowmaking[106] and, generally, the colder the temperature the less costly it is to make snow. Under future climate scenarios these conditions will be met on fewer days.

Water availability could increase or decrease with climate change, depending on how precipitation is affected. If precipitation increases in the winter as rain then more water may be available for snowmaking. Less water could be available if there is no change in precipitation or if precipitation decreases. With warmer summers, there may also be less water available in the streams and ponds during winter to make snow. It takes 150,000 to 180,000 gallons of water to cover one acre of ski trails with one foot of snow. Depending on the rate and season (fall or spring) at which water is withdrawn from the streams, this amount of water withdrawal can lead to decreased fish habitat area and increased ice formation as well as increased scouring of the river bed, leading to fish egg damage.[107]

Current and future advances in technology, as well as other mitigation strategies, can address some of these problems. For example, technology exists that can increase the average freezing temperature of water and increase the quantity of snow made per unit of water used.[108] This may allow ski areas to make snow under moderately warmer conditions and allow them to save energy and energy costs. In addition, as snowmaking equipment becomes more energy efficient, ski areas will also be able to cut down on costs. These types of technology improvements could help alleviate some of the negative affects of climate change for ski areas, at least in the

Rainbow, brook and brown trout habitat may be partially or completely eliminated in the White Mountains as well as other areas in New England by the middle to the end of the next century if warming occurs as projected in current climate change models. (Photo: Charlie Fellenbaum).

short term. Increasing the size of ponds from which water can be withdrawn for snow making, as has already been started in some ski areas, would mitigate damage to fish habitat from snowmaking.

An in-depth study of the impact of global warming on downhill skiing in the Laurentians in Quebec used temperature scenarios similar to the higher temperature scenario presented for the White Mountains in this report (see Figure 1).[109] In addition, precipitation, snow-cover and snowmaking conditions were included as driving factors in the analysis. With warming of from 7.6 to 9.3°F and increased precipitation ranging from 0 to 16 percent, the study found a reduction of the ski season length of 40 to 89 percent with a minimum financial loss of $10 million (Canadian) and a maximum loss of the virtual elimination of the ski industry in the area. Ski season length was little affected until the average winter temperature increased by 3.6°F (2°C).

Recreational fishing

Recreational fishing in the White Mountains region could be significantly affected by climate change. Climate change may have direct effects on fish habitat and populations, especially in cold-water rivers and streams, due to the impact of warmer temperatures and changes in precipitation on stream temperature and flow rates.[110] Cold-water fish species common to the White Mountains region may be unable to survive a significant warming of water temperature, though species differ in their degree of tolerance. Brook trout, for example, have strict temperature requirements and may be particularly vulnerable to climate change. Brown trout and rainbow trout can tolerate a wider temperature range than brook trout, but are still limited by temperature, especially during spawning.[111] Changes in timing or amount of precipitation may affect the quantity and quality of water in streams which could also cause deterioration of habitat for trout.

The economic impact of losses in trout habitat could be significant. Nationally, an estimated 35.6 million people spent 511 million days fishing in 1991. In New England, two million people devoted 24 million days to fishing and spent an average of $674[112] each, or a total of $1.3 billion. Of the two million people who fished in New England in 1991, 35 percent traveled from out of state to do so.[113]

Climate change is expected to cause a decline in cold-water fish habitat by increasing the temperature of streams to levels exceeding the thermal tolerance limit for cold-water fish, making some species, like brown and brook trout, unable to survive the warmer waters. The loss should be greater along the southern borders of a species' natural range where temperatures are already close to the thermal tolerance. According to a study by the Environmental Protection Agency, loss of habitat for cold-water fish may be significant throughout their range.[114] Rainbow trout, brook trout, and brown trout are the most important cold-water fish for recreational fishing in the New England area and several states could potentially lose all habitat suitable for these species (Figure 5). Cool-water guilds, which include walleye, Northern Pike, and yellow perch, will probably not be affected in the New England area.

Stream flow rates could also be affected by climate change. If warmer temperatures and changes in precipitation patterns cause severe floods in spring or extreme low flows in late fall or winter, then species may be excluded from occupying sections of stream where they would otherwise be expected to occur.[115] Low water levels and reduced flows could decrease the availability of winter habitat, decrease the reproductive success of fish, and reduce food availability.[116] Low flows can prevent the migration of trout to their spawning grounds as well as reduce the area available for spawning. Reduced flows and ice formation in winter may result in the suffocation, desiccation, and freezing of trout eggs. When river depths are too shallow, ice formations can rip the eggs from the stream bottom. Reduction in habitat can cause crowding and stress-induced disease, and it can also lead to stranding (when a segment of stream is too shallow or frozen preventing fish from passing through to another area). Flooding scours stream bottoms and can destroy eggs as well as diminish food supply.[117]

Reproduction could also be directly affected by warmer temperatures. Temperature is one of the most important variables in reproduction. Some species will spawn only within a narrow temperature range that is lower than what they can tolerate as adults. Warming could affect this vulnerable stage in the fish life-cycle before affects to adult fish become important.[118]

Warmer stream temperatures would suggest that cool- or warm-water fish could replace cold-water fish. However, water velocity could limit what species are able to colonize these areas. For example, trout typically live near headwaters of streams where the topographic gradient is steep, water velocity is fast, and the bottom is gravely or rocky.[119] Many warm-water species require a medium to low gradient with medium to slow water velocities in addition to appropriate water temperatures.[120] Therefore, even if water temperatures in an area become ideal for warm-water species, they may still fail to expand their habitat into the area due to streams running too quickly. In streams where water flow has been slowed because of the construction of dams or other water diversions, warm-water species have been able to expand their habitat to the detriment of trout.[121]

Potential benefits to fish could occur at the northern end of the range in Canada where warmer temperatures could increase growth, productivity, and maturation rates of fishes. One study estimated that productivity could increase by about 10-20 percent per 1.8°F (1°C) increase in temperature, as long as other factors that limit growth, such as nutrient and food supply, continue to be available as climate changes.[122]

How these effects will subsequently translate into behavioral changes on the part of anglers is difficult to gauge. If the species composition of a particular stream changes from cold-water to warm-water fish, anglers may choose to fish in the same location for different species, travel further north or move to higher elevations to fish for the same species or change habits all together.

Loss of Habitat for Cold-Water Fish

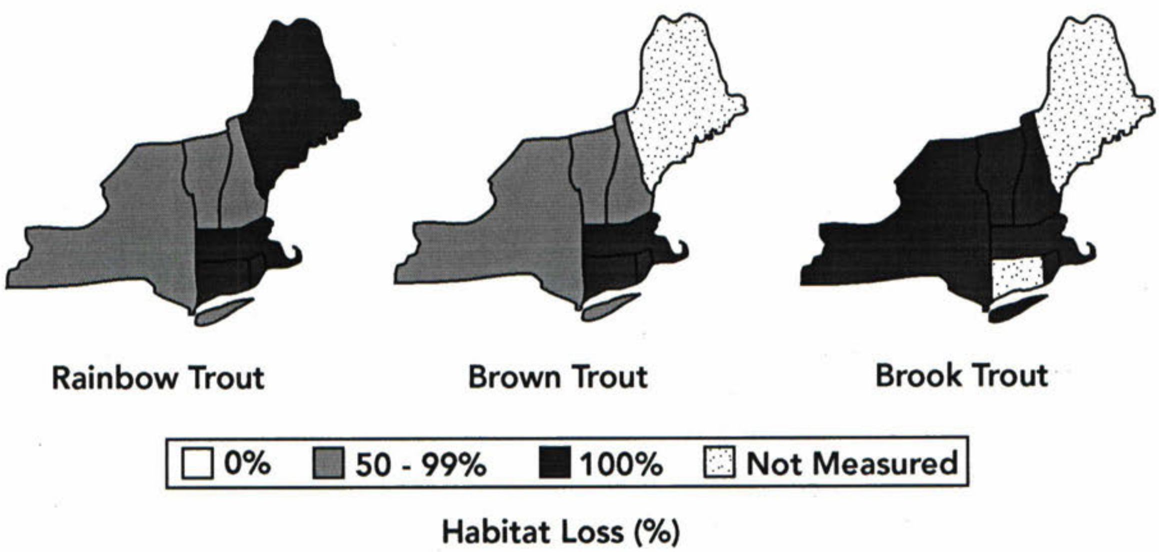
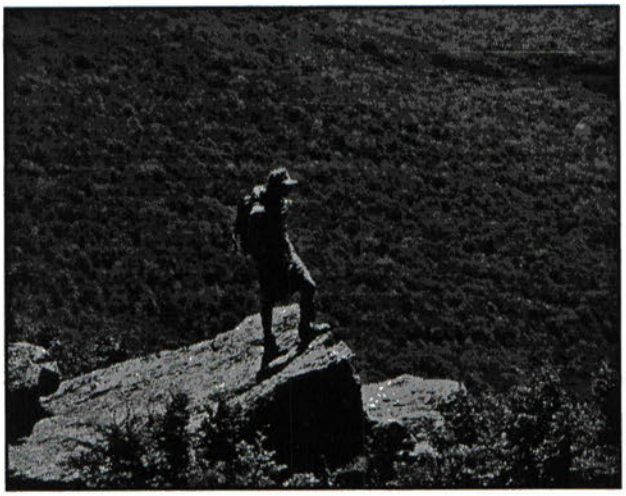


Figure 5. Percent loss of habitat for rainbow, brook and brown trout in New England according to one scenario from a 1995 EPA study on the ecological impacts of climate change on freshwater recreational fishing using the GFDL (Goddard Fluid Dynamics Laboratory) equilibrium climate model at double CO_2 concentrations as input (see Figure 1). This study did not consider brook or brown trout in their baseline information for Maine or brook trout for Connecticut.

Source: US EPA, Ecological Impacts from Climate Change: An Economic Analysis of Freshwater Recreational Fishing, EPA 220-R95-004, April, 1995.



While global warming will probably lead to a longer hiking season for the White Mountains region, it might also be much less enjoyable due to hotter, and potentially drier, smoggier summers and larger areas with dead and dying trees. (photography: Paul O. Boisvert).

Generally, cold-water fishing is more valuable than warm-water fishing, so a gain of an acre in warm-water habitat is not equal to a loss of an acre of cold-water habitat.[123] In the worst case result of the EPA model on the potential impact of climate change on recreational fishing,[124] the number of cold- and cool-water fishing days (defined as person-days spent fishing) nationally declined by 50 million while the number of warm-water and rough guild fishing days increased by 64 million. However, because of the greater value placed on cool- and cold-water guilds, there was a net annual economic loss of $320 million.

Hiking and nature walking

Hiking and camping are popular summertime activities in the White Mountains region. Climate change may significantly affect this experience. Warmer temperatures will probably lengthen the hiking season by increasing the number of snow-free days in the mountains. However, if the disturbance and declines discussed elsewhere in this report do become more common,[125] the quality of the natural experience may be significantly decreased. Numbers of dead and dying spruce and fir trees, pest and pathogen outbreaks, more frequent fires, and more frequent droughts in summer may all increase, contributing to a more open but significantly less attractive forest for recreation.

Warmer temperatures could also exacerbate already deteriorating air quality. Much of the excitement of hiking to a peak or driving to the top of Mt. Washington is derived from the sweeping panorama visible from the top. However, visibility is decreased by the particulate component of pollution. Both particulates and ozone have already become a problem in the White Mountains region and both could be exacerbated by warming temperatures in the summer (see Box 6). For example, according to an ongoing study conducted by the Appalachian Mountain Club[126] some higher elevation sites, includ-

Box 6. Ground-level Ozone

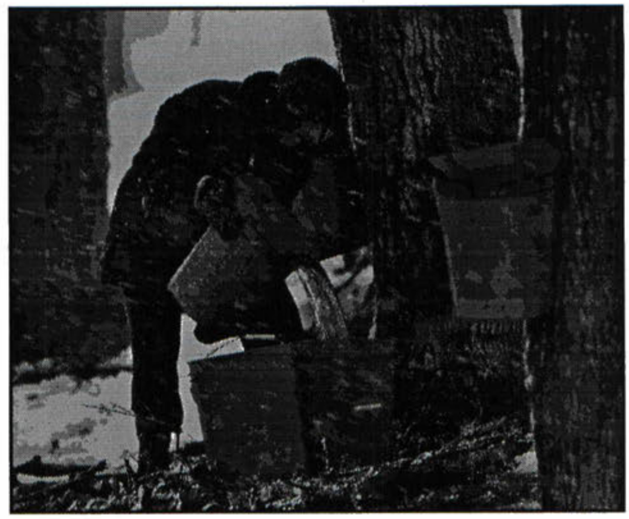
Ozone is a strong oxidant formed by reactions of nitrogen oxides (NOx) with hydrocarbons in the presence of sunlight. Fossil fuel use, primarily from automobile engines and industry, produces most of the compounds that result in ozone formation. Ozone, formed near the "ground level," can be damaging to humans, vegetation and animals. Elevated ozone concentrations, especially common during the summer months, have become a serious problem—not only in urban areas, but in remote, high-elevation forests like the White Mountains due to long-distance transport processes. Furthermore, increases in temperature are known to enhance ozone production,[129] suggesting that climate change may exacerbate this problem. Ground-level ozone causes irritation and damage to membranes of the respiratory system and eyes in humans and other animals. High ozone concentrations can lead to damage to needles and leaves, contributing to reduced growth and seed production and increased susceptibility to other problems, such as insects and diseases.[130] As such, it is thought to be a contributor, along with acid deposition, to dieback and decline of forest species, especially conifers such as eastern white pine.[131] Current monitoring of ozone-related damage to plants and trees in New England shows the greatest injury is found where ozone concentrations are highest and air quality is poor (e.g., Southern New England especially Connecticut).[132] Air quality may improve if emissions of sulfates (SO_2), nitrates (NOx) and volatile organic compounds (VOCs) are decreased. Reductions in SO_2 are already occurring at a national level, which should aid in haze reduction - though warming could reduce the benefit of these reductions.

ing Mt. Washington, have ozone concentrations comparable to those of urban areas far to the south[127] In 1988, a particularly hot and humid summer in New Hampshire with high ozone concentrations and lots of haze, the heat combined with poor air quality may have led to the decrease in the number of hikers and other visitors to the White Mountains National Forest that was observed that year.[128]

CLIMATE CHANGE AND THE MAPLE SYRUP INDUSTRY

Sugaring, the harvesting of sugar maple sap to produce maple syrup, is a tradition in the White Mountains region and throughout New England that dates back to pre-colonial days. To residents and tourists alike, it wouldn't be spring in New England without the Maple syrup season. Yet climate change could seriously affect the maple syrup industry in the White Mountains region as well as New England as a whole, shortening the season and decreasing the profitability of the industry.

One important reason that maple syrup production could be so susceptible to climate change is that strong sap flow only occurs when there is a sharp difference between day and night temperatures: optimal sap flow in sugar maple is dependent on a prolonged early spring period with cold (less than 25˚F or -3.9˚C) nights and warm (more than 40˚F or 4.4˚C) days.[133] As discussed above (see Page 10), one impact of climate change may be that there will be less difference between day and night temperatures (diurnal range). So, while the timing of the sugaring season depends on latitude - in the White Mountains region of northern New Hampshire the season typically runs from mid March to mid April, while in southern New Hampshire the season typically runs from the end of February to the beginning of April[134]— the length of the season depends on the number of cold nights followed by warm days. With a decrease in the diurnal range of temperatures, the length, and therefore profitability, of the maple syrup season is threatened. If warming were to occur predominately at night, the number of days of optimal syrup flow will decrease considerably more than if the warming occurred by the same amount in the day as the night.



Maple syrup production or sugaring is a cherished tradition in New England as well as being a popular tourist attraction. Warmer nights and earlier springs may shorten the maple syrup season. In addition, sugar maple itself is susceptible to increased mortality as a result of climate change. (photography: Paul O. Boisvert).

While it is essential to have optimal flow days

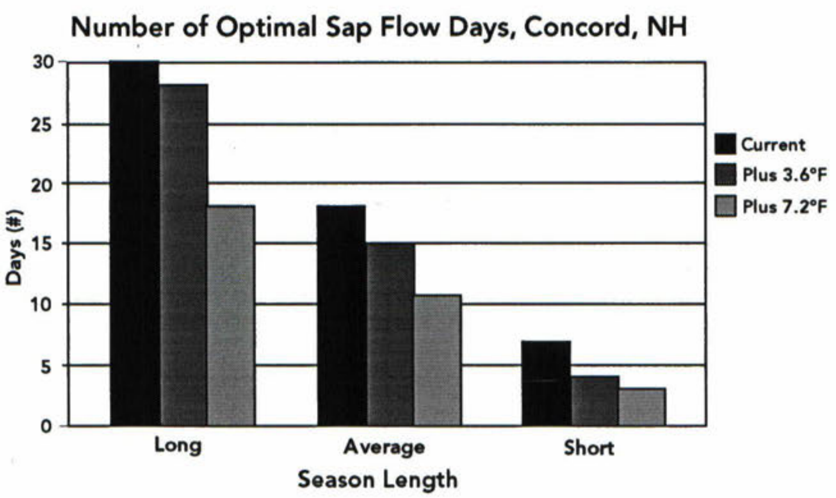


Figure 6. Number of optimal sap flow days as defined by days between January and May with maximum temperature over 40°F and minimum temperature under 25°F under current climate conditions and two predominantly nighttime warming scenarios (twice as much warming during the night as during the day). Warming scenarios are for plus 3.6°F (2°C) and 7.2°F (4°C). Values are given for historically long, average and short seasons for Concord, NH between the years 1948 and 1992.

Source: Weather data obtained from the Northeast Regional Climate Center, Cornell University, Ithaca, NY

Box 7. The economic and social value of the maple syrup industry in New Hampshire

Sugarbush operators (maple syrup producers) can be found throughout New England. Operations range in size, from those with a few trees in the backyard using traditional methods to collect and boil down the sap, to large farms with thousands of trees employing the latest in automated collection and production methods. While maple syrup production is not yet reported separately in the US Census, there are about 600-700 sugarhouses in New Hampshire plus a large number of small backyard operations (Hank Peterson, Maple Producers Association, Peterson Sugar House, personal comm.). Since maple syrup is harvested in early spring, it is important to the farmer as it provides the first source of income during the year. The value of maple syrup production in New Hampshire in 1995 was $2,112,000 and peaked in 1992 at $3,093,000 (North American Sugar Maple Association). Although the price of syrup and the price of production fluctuate, often depending on fuel costs, the profit margin remains about constant each season.

The maple syrup industry is increasingly important to tourism with many sugarbushes and sugarhouses open to the public during the season. Sugaring in New England is a tradition dating back to the Native Americans who boiled down the maple sap and used the syrup as an important part of their diet. Maple syrup was the most common sweetener available during the colonial period before cane or beet sugar was available. Today, maple syrup remains a symbol of New England. As Tom Slayton, editor of Vermont Life magazine, put it, "That early spring burst of activity unfailingly ties Vermonters to the land and the rhythm of the seasons. It's our particular form of alchemy, I guess, the alchemy of wood-fired arch and steaming maple sap that turns our grimmest season and the year's hardest labor into pure gold."[142]

The combination of climate change, sugar maple declines, and nighttime warming driven by greenhouse gases may decrease the profitability of the maple syrup industry in much of New Hampshire. Since many operations are already small and marginal in terms of profit, as seasons worsen, the syrup industry may decline. As warming continues, the maple syrup industry will probably become more profitable further north into Canada. In fact, this trend is already apparent as maple syrup is now being produced in more northerly areas of Canada where it has never been possible before.[143]

While the blow may not be severe to the economy of New Hampshire as a whole, individual towns, as well as the tourism industry in general, could feel repercussions. Beyond economic losses, maple syrup is one of the defining qualities of life in New England, its decline would be sorely felt.

for a successful maple syrup season, a typical season also includes days that would not be counted under the definition of optimal flow. A typical season lasts on average 33 days of which about 18 are optimal by the definition used in this report (see Figure 6). Because of the short season length, a loss of even one optimal flow day can be significant since there is a direct relationship between number of optimal flow days and total season length. For example, one sugarbush operator calculated a loss in production of 20 percent during one season which experienced 6 nights with above-freezing temperatures.[135] In another instance, during the 1992-1993 season, a harsh winter (cold and heavy snow) delayed the beginning of the season by about two weeks, while warm weather stopped it one week early This resulted in a total production loss of about 50 percent. The number of optimal flow days—according to the definition in this report—using only weather information, would have been 8, well below the average number of such days (Figure 6).[136]

To find out how optimal flow days would be affected by climate change, we looked at temperature records for Concord, in south-central New Hampshire, an area where a large number of sugar maple farms operate. As a baseline, we used temperature records for the years 1948 to 1992 and applied scenarios of increased temperature occurring at a rate that was twice as much during the night as during the day. This is the ratio at which current warming is occurring in North America.[137] In this scenario, we defined optimum flow days as those with night temperatures less than 25°F (-3.9°C) and day time temperatures more than 40°F (4.4°C). As can be seen in Figure 6, under the predominantly nighttime warming scenarios, the number of optimal sap flow days would be reduced considerably, to 15 days for the 3.6°F scenario and to 11 days for the 7.2°F scenario, representing a loss of 17% and 39% in a season of average length.

While the difference between nighttime and daytime warming may decline over time, especially if emissions of sulfates decrease, overall temperature increase could still negatively affect maple syrup production. Increased temperatures could cause buds to break earlier in the season than they currently do. Once buds break, the sap collected produces syrup which is bitter and cannot be marketed.[138] If the season begins earlier as well, this would merely shift the timing of the whole season earlier. However, if warming is not uniform between seasons (e.g., a cold winter followed by a warm spring), the season could be shortened.

Maple syrup production is also threatened by tree decline.[139] As trees decline, the rate and quality of sap flow has been shown to decrease.[140] Because sugar maple is found primarily on moist rich soils and is not particularly tolerant to drought, sites currently suitable for sugar maple growth may become unavailable as soils become drier due to climate change. New sites could become available further north of the White Mountains region and in Canada. Decreased snow cover is also detrimental to syrup production, since snow insulates the ground, keeping it frozen longer and keeping buds from breaking early.[141] However, some climate models predict increased amounts of snow fall during the winter, which could counterbalance increased melting due to warmer temperatures.

CLIMATE CHANGE AND THE TIMBER INDUSTRY

Much of the White Mountains region is forested. These forests are owned and managed by private and public landholders including individuals, large timber companies, and the state and federal governments. The largest single management unit in the White Mountains region is the White Mountain National Forest, which is managed for the multiple uses of recreation, ecosystem health and biodiversity, and wood products production. Timber is harvested for use in furniture, specialty products,

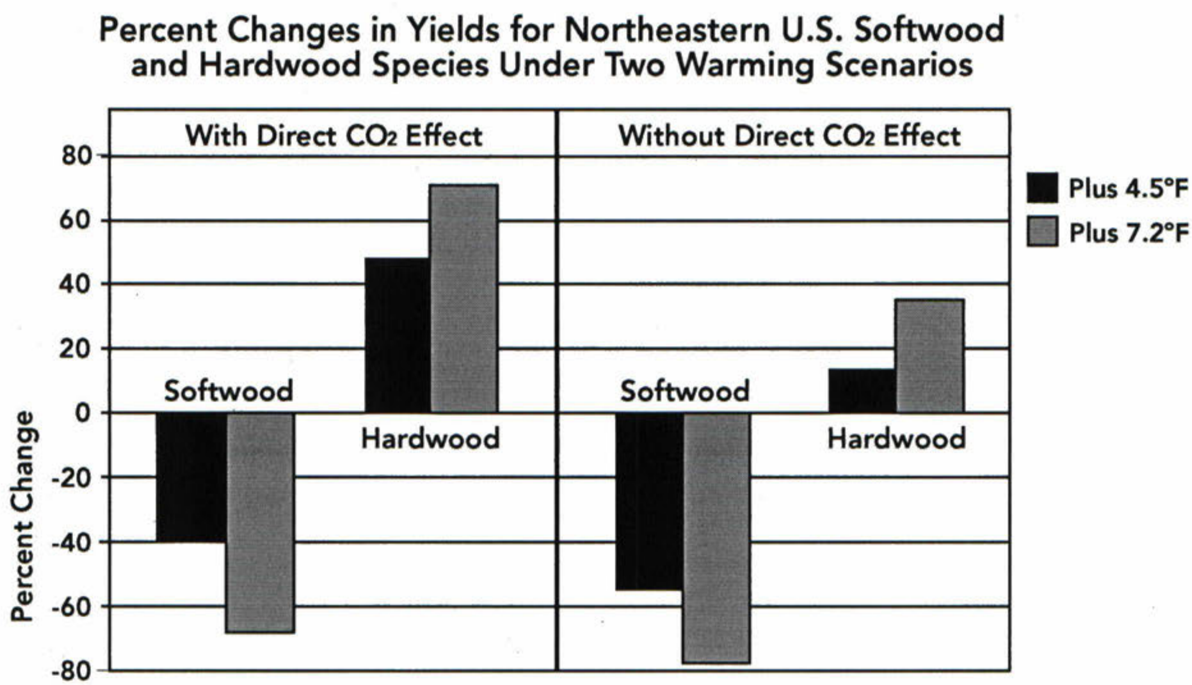


Figure 7. Change in yield under two warming scenarios, plus 4.5°F (2.5°C) and plus 7.2°F (4.0°C) with and without direct CO_2 effects in the northeastern United States using forest gap models as input to the FASOM model, a dynamic nonlinear programming model of the forest sector in the United States.

Source: Callaway, M Smith J, and Keefe, S, (1995) *The Economic Effects of Climate Change on US Forests*, RCG/Hagler Bailly, Boulder CO, Prepared for Adaptation Branch, Climate Change Division, Office of Policy, Planning and Evaluation, US EPA, Washington, DC Contract No. 68-W2-0018.

building material, fuelwood, and pulp for paper production. Major commercial forest types that occur in the White Mountain National Forest include northern hardwoods, the most abundant type in the Forest with over 200,000 acres under management, spruce-fir communities, found at higher elevations, and some hemlock. Outside of the National Forest, much of the area is former agricultural lands that have reverted to forest and are held by a variety of small and large private owners. White pine is found in many of these previously disturbed areas throughout the White Mountains region. In New England as a whole, papermaking, sawmilling, logging, and wood product fabrication employ about 250,000 individuals.[144] The output of these industries totals about 9 percent of the New England's manufacturing production.[145] The forest products industry is the third largest in New Hampshire in terms of revenues and fourth in terms of employment.[146]

An EPA study on the economic effects of climate change on US forests by region[147] showed decreased softwood (which includes spruce, fir, hemlock and white pine) yields but increased hardwood yields (including northern hardwoods) with increased temperature, when applied to the northeastern United States (Figure 7). When the model included the possible direct effects of CO_2 on growth and productivity, yields were less depressed for softwoods and increased for hardwoods. However, there is evidence in the research literature that direct CO_2 effects cannot be applied equally to all forest species over the long term, and with higher than double CO_2 concentrations (see page 13).

The US Forest Service also recently performed an analysis, by forest type and by region, of the impact of climate change on forest productivity and timber supply in the United States.[148] Assuming that forest type would not change, productivity and timber supply increased for both softwood and hardwood forests in the Northeastern United States.

Both the EPA and the Forest Service studies looked specifically at how productivity (the amount of carbon or biomass produced by trees) could change *assuming current forests are not replaced by other species.* Neither model examined how forest species and type could change as a result of climate change. As was discussed in more detail earlier in the report (see Page 10 and Figure 3), climate change may mean that many tree species may not be able to successfully reproduce and grow in their current locations. Increased disturbance, which may also accompany climate change - including increased risks from fire, pest and pathogen outbreaks and storm damage - could also lead to changes in forest species and type. In addition, as species shift there will be an increase in tree mortality, which would also decrease productivity, especially in the short-term.

Because we know how individual species react to climate, soil conditions and disturbances, it is possible to make some preliminary estimates on how trees important to the timber industry in the White Mountains region could be affected by climate change. White pine and red oak, currently the two most important timber species in New England as a whole, could increase in the White Mountains region in a warmer climate: oak because of warmer, drier conditions and white pine because it tends to become dominant after disturbances which may increase due to climate change. Quality northern hardwoods (sugar maple, ash and yellow birch) could decline due to changes in climate, especially extreme or unusual weather. Spruce and fir could decline as warming temperatures push the trees upward in elevation (see Box 4, page 13). Beech and red maple, which may be more tolerant of warmer drier conditions, could increase but are much less valuable as timber resources.

Because of the many uncertainties discussed, the ultimate economic impact of the various changes in forest types on the timber industry is hard to predict. The timber industry in New England has been remarkably flexible in its ability to adapt to changes in timber species harvested in the past. The industry thus may be able to adapt to potential losses of spruce and fir and some northern hardwood species, by potential increases in white pine or oak. However, during transition periods between forest species, productivity could be greatly reduced. At this point we can only suggest that there are potential risks and benefits to the timber industry of this region and that further development of forest models is necessary before more accurate economic models can be developed.

CONCLUSIONS

A scientific consensus exists that human-generated emissions of greenhouse gases to the atmosphere are probably having a discernible impact on global climate, and that influence is expected to increase in the future. If predictions from climate models become reality, many dimensions of our world will change. While there is a range of plausible outcomes for ecosystems and society, many scenarios point to significant risks to natural resources and our quality of life .

The White Mountains region provides year-round recreational opportunities for visitors and a satisfying way of life for residents, largely due to an abundance of natural resources. In turn, these natural resources are, to a great extent, dependent on climate. We are so used to climate remaining fairly constant during our lifetimes that we have little prior knowledge to guide us when it changes. For the White Mountains region there is a range of possible scenarios for the future.

The most optimistic see the region benefiting in some respects. Through a combination of long growing seasons, wet summers, and carbon dioxide fertilization, these scenarios suggest that trees and forests will become more productive, will remain healthy and will actually store more biomass as climate change proceeds. Ski seasons may shorten, but this will be compensated for by longer summer recreation seasons. Some new tree species may be established and some tree species currently occurring in the region may die off, but on balance forests would remain healthy and people will continue to live, work and enjoy the White Mountains much as they always have.

Yet there is a darker vision for this region, another potential outcome of climate change. In this scenario, as temperatures rise, weather becomes more extreme and less predictable. Winters with heavy snow are accompanied by early spring warming to produce large-scale flooding. Longer, hotter, summers lead to drought conditions by early fall increasing the susceptibility of trees to disease and forests to wildfires. Fall foliage displays are muted and ski seasons are shortened. Thawing during winter damages sugar maples and other tree species. Warmer nights and earlier springs shorten the maple syrup season making syrup production unprofitable in the region. Summer recreation is less pleasant due to increased smog and uncomfortably hot temperatures. Already existing pollution, like acid rain and ozone, combine with climate change to cause widespread forest declines leading to forest morbidity and mortality. New forests are slow to recolonize disturbed areas, leading to large areas of weeds, grasses and shrubs.

We don't know at this point whether either of these scenarios or one in between might really unfold if climate change continues as projected. Because the risks are great, the prudent course would be to try to avert a potentially disastrous result. This implies action to slow and reduce the emissions of greenhouse gases at local, national and international levels.

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1 The discussion of climate change science and its predictions for North America and the White Mountains for this report is drawn extensively from the Intergovernmental Panel on Climate Change (IPCC) assessments. The IPCC is an international group of thousands of scientists that was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988, to assess scientific information about climate change relevant for international and national policy formulation. Since 1988, the IPCC has published numerous reports, including the Second Assessment Report in 1995 which provided a comprehensive review and analysis of the science of climate change, the potential impacts to natural and human systems, and mitigation strategies. For more information, see Climate Change 1995: The Science of Climate Change. (Eds. JT Houghton, LG Meira Filho, BA Calander, N Harris, A Kattenberg and K Maskell) Cambridge University Press, Cambridge. 571p. For an overview, refer to the "Summary for Policymakers".

2 The climate models used to generate this range of temperature predictions are described in Kattenberg A, Giorgi F, Grassl H, Meehl GA, Mitchell JFB Stouffer RJ, Tokioka T, Weaver AJ and Wigley TML (1995). Climate Models - Projections of Future Climate. In Climate Change 1995: The Science of Climate Change. (Eds. JT Houghton, LG Meira Filho, BA Calander, N Harris, A Kattenberg and K Maskell) Cambridge University Press, Cambridge. p. 285-357. This citation is a key chapter in the Intergovernmental Panel on Climate Change's 1995 report on the science of climate change. It is a comprehensive review of current climate models with a discussion of their reliability reflecting the work of hundreds of researchers from a diverse group of countries

3 Ibid.

4 see Technical Summary in Climate Change 1995: The Science of Climate Change. (Eds. JT Houghton, LG Meira Filho, BA Calander, N Harris, A Kattenberg and K Maskell) Cambridge University Press, Cambridge. p.9-49.

5 The following discussion on climate change science is drawn from the IPCC Second Assessment Report (1995), see note 1 above.

6 Ibid.

7 Kattenberg et al., 1995.

8 IPCC, 1995.

9 Ibid.

10 Emissions of sulfate aerosols may decrease, especially in developed countries, in the next 100 years if strategies to reduce acid precipitation are effective. Predictions have also been made that there will be a continuing transition away from coal use as fuel technology advances. Since sulfate aerosols are relatively short-lived in the atmosphere, if emissions are decreased, their cooling effect will decrease quickly. Ironically, reduction of this form of pollution could result in greater warming due to greenhouse gases. See "Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emissions Scenarios" (Eds) J.T. Houghton, et al Cambridge University Press, Cambridge, 1995 for examples of various emissions scenarios (the six IS92 scenarios) including those where sulfate aerosols are reduced. One scenario where sulfate aerosols were held constant is also included in this report.

11 IPCC, 1995

12 Climate Change, 1994 (see note 10).

13 Kattenberg et al., 1995

14 Ibid.

15 See Figure 1 "Sources" for climate model references.

16 Kattenberg et al., 1995

17 Ibid.

18 Ibid.

19 In general, the effects of intense rain on the landscape include mudslides, erosion and tree falls. However, in the White Mountains region specifically, erosion is often limited to streambanks, and mudslides are currently uncommon occurrences (personal communication, Dr. Steven Fay, Forest Soil Scientist, White Mountain National Forest, Laconia, NH)

20 Kattenberg et al., 1995.

21 For an excellent review and analysis of climate and precipitation trends in the United States for the last century based on extensive weather station data, see Karl TR, Knight RW, Easterling DR and Quayle RG (1995). Trends in U.S. climate during the twentieth century. Consequences 1:3-12.

22 Kukla G and Kar, TR (1993) Nighttime warming and the greenhouse effect. Environment, Science and Technology, 27(8): 1469-1474.

23 There is an extensive literature on the relative rapidity of climate change projected to occur with greenhouse gas warming. For a general overview, see Gates DM, (1993). Climate Change and Its Biological Consequences, Sinauer Associates, Inc. A more technical collection of papers can be found in Huntley B, Cramer W., Morgan AV, Prentice HC, and Allen JRM, (eds) (1997). Past and Future Rapid Environmental Changes: The Spatial and Evolutionary Responses of Terrestrial Biota. Springer-Verlag, Berlin. For more specific information on climate change in the White Mountains, see the review in Davis, MB (1985). History of the vegetation on the Mirror Lake watershed. pp. 53-65. In GE Likens (ed.) An Ecosystem Approach to Aquatic Ecology: Mirror Lake and its Environment. Springer-Verlag New York.

24 The historical changes in vegetation (paleoecology) in the White Mountains has been extensively studied at a variety of sites including Mirror Lake in the Hubbard Brook Experimental Forest, reviewed in Davis, 1985 and in a series of lakes and ponds in New Hampshire, reviewed in Spear, RW (1989). Late-Quaternary History of High-Elevation Vegetation in the White Mountains of New Hampshire. Ecological Monographs, 59:125-151 and Spear, R., M Davis, and LCK Shane (1994). Late Quaternary History of Low-and Mid-Elevation Vegetation in the White Mountains of New Hampshire, in Ecological Monographs, 64(1): 85-109. These studies of pollen and plant macrofossils found in bog sediments enable scientists to reconstruct the history of vegetation over the last approximately 14,000 years.

25 Davis, 1985.

26 Davis, 1985.

27 IPCC, 1995 and see p. 14 for a discussion of how greenhouse-gas mediated climate change could result in higher incidence and severity of disturbances.

28 A description of red spruce's (*Picea rubens* Sarg.) current range can be found in Burns RM and Honkala BH, tech. Coords. (1990). Silvics of North America, Volume 1. Conifers Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C. 250pp.

29 This estimate is from Goldthwait RP (1976). Past climates on "the hill". Mt. Washington Observatory Bulletin, March and June issues, as quoted by Spear RW (1989). Late-Quaternary History of High-Elevation Vegetation in the White Mountains of New Hampshire. Ecological Monographs, 59:125-151.

30 These estimates are derived from model simulations for continental interiors of North America, see Davis, 1985; COHMAP Members (1988). Climatic changes of the last 18,000 years: Observations and model simulations. Science 241:1043-1052. Spear, RW, (1989). Late-Quaternary History of High-Elevation Vegetation in the White Mountains of New Hampshire, in Ecological Monographs, 59(2): 125-151 It is assumed that the White Mountains behaved in a consistent fashion with the results given.

31 Davis, 1985; Spear, 1989.

32 Davis, 1985; Spear et al., 1994.

33 The forests and ecosystems of the White Mountains region are some of the most studied and best characterized of any in the world. This is in large measure because of long-term studies of forests and ecosystems that have been performed at the Hubbard Brook Experimental Forest (HBEF) in Woodstock, New Hampshire located in the White Mountains region. The HBEF was established by the US Forest Service in 1955 and since that time has generated a continuous long-term data set that includes information on temperature, precipitation, soil, hydrology, nutrient cycling and vegetation. Studies at the watershed level have been key to our understanding of ecosystem dynamics and forest succession both in the White Mountains itself and as applied to forests the world over. In addition, if climate change occurs as has been projected by climate models, the HBEF would be an excellent site for monitoring changes in vegetation, soils, and nutrient cycling that may result due to the extensive baseline information that exists there. For more information on the vegetation, ecosystem dynamics and forests of the White Mountains and Hubbard Brook, see Bormann FH and Likens GE (1979). Pattern and Process in a Forested Ecosystem. Springer-Verlag, New York. 253p., G E Likens (ed.) (1985) An Ecosystem Approach to Aquatic Ecology: Mirror Lake and its Environment. Springer-Verlag New York, and Likens, GE and Bormann, FH, (1995). Biogeochemistry of a Forested Ecosystem. Second Edition. Springer-Verlag New York. 159pp. See Box 3 for more details.

34 For an overview of how forests and biomes are predicted to change with projected climate change, see the Forests chapter in the IPCC, 1995: Kirschbaum MUF, Fischlin A et al. (1995). Climate Change Impacts on Forests. In Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses (Eds. RT Wilson, MC Zinyowera, and RH Moss) Cambridge University Press, Cambridge. p. 95-130.

35 Bormann FH and Likens GE (1979). Pattern and Process in a Forested Ecosystem. Springer-Verlag, New York. 253pp.

36 Likens GE and Bormann FH (1995). Biogeochemistry of a Forested Ecosystem. Second Edition. Springer-Verlag New York. 159pp. In addition, for a listing of the hundreds of peer-reviewed publications, dissertations, and theses that have emerged from

Hubbard Brook Ecosystem Study, see "Publications of the Hubbard Brook Ecosystem Study" compiled by Phyllis Likens in 1997 which can be obtained from the Institute of Ecosystem Studies, Millbrook, NY.

37 G E Likens (ed.) (1985) An Ecosystem Approach to Aquatic Ecology: Mirror Lake and its Environment. Springer-Verlag New York.

38 Leak WB and Smith ML, (1996). Sixty-years of management and natural disturbance in a New England forested landscape. Forest Ecology and Management, 81: 63-73.

39 MAPSS is a computer model that maps biomes on the basis of climate. Thus, depending on what the pattern of temperature and precipitation in a particular location is, MAPSS determines what type of trees and other vegetation should grow there. To learn more about this model, see Neilson RP (1995). A model for predicting continental-scale vegetation distribution and water balance. Ecological Applications 5:362-385 and VEMAP Members (1995). Vegetation/ecosystem modeling and analysis project: Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. Global Biogeochemical Cycles 9:407-437. as well as the chapter on forests in the IPCC synthesis Kirschbaum MUF, Fischlin A et al. (1995) Climate Change Impacts on Forests. In Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses (Eds. RT Wilson, MC Zinyowera, and RH Moss) Cambridge University Press, Cambridge. p. 95-130.

40 Ibid.

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42 For a review, see Johnson AH, Cook ER, Siccama TG (1988) Climate and red spruce growth and decline in the northern Appalachians Proc. Natl. Acad. Sci., USA 85: 5369-5373.

43 For a review, see Friedland AJ and Battles JJ (1987). Red spruce (*Picea rubens* sarg.) decline in the northwestern [sic] United States: Review and recent data from Whiteface Mountain. In Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences. Krakow, Poland (23-27 March, 1987), Kairiukstis L, Nilsson S, and Straszak A, (Eds.), IIASA, A-2361 Luxenburg, Austria.

44 Friedland and Battles, 1987; Johnson et al., 1988.

45 For reviews, see Johnson AH, McLaughlin SB, Adams MB, Cook ER, DeHayes DH, Eagar C, Fernandez IJ, Johnson DW, Kohout RJ, Mohnen VA, Nicholas NS, Peart DR, Schier GA, and White PS (1992). Synthesis and conclusions from epidemiological and mechanistic studies of red spruce decline. In Ecology and Decline of Red Spruce in the Eastern United States (C Eagar and MB Adams, eds.) Springer-Verlag, New York. p.385-411. Friedland and Battles, 1987; Perkins TD, Klein RM, Badger GJ, and Easter MJ (1992). Spruce-fir decline and gap dynamics on Camels Hump, Vermont. Canadian Journal of Forest Research 22: 413-422 as well as the report of the U.S. National Acid Precipitation Assessment Program (1991).

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48 Johnson et al., 1992; Berlyn GP, Anoruo AO, Johnson AH, Vann DR, Strimbeck GR, Boyce RL and WL Silver (1993). Effects of filtered air and misting treatments on Cuticles of Red Spruce needles on Whiteface Mountain, NY. Journal of Sustainable Forestry 1:25-47; Jacobson JS, Heller LI, Yamada KE, Osmeloski JF, Bethard T and Lassoie JP (1990). Foliar injury and growth response of red spruce to sulfate and nitrate acidic mist. Canadian Journal of Forest Resources 20: 58-65.

49 Johnson et al., 1992.

50 Hamburg SP and Cogbill CV (1988). Historical decline of red spruce populations and climatic warming. Nature 331: 428-431.

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53 The TEM includes both nitrogen and carbon dynamics thus making this model particularly sensitive to the increased availability of nitrogen in the soil due to increased decomposition in warmer temperatures. For a description of the model and its application to New England, see Melillo JM, McGuire, AD, Kicklighter, DW, Moore, B, Vorosmarty, CJ, Schloss, AL (1993). Global climate change and terrestrial net primary production. Nature 363: 234-240.

54. Aber J D, K J Nadelhoffer, P Steudler, and J M Melillo (1989). Nitrogen saturation in northern forest ecosystems. Bioscience 39(6):378-386; Magill AH, J D Aber, J J Hendricks, R D Bowden, J M Melillo and P A Steudler (1997). Biogeochemical response of forest ecosystems to simulated chronic nitrogen deposition. Ecological Applications 7(2):402-415.

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58 Bazzaz et al., 1996; For a specific example, see Curtis PS, Klus DJ, Kalisz, S and SJ Tonsor (1996). Intraspecific variation in CO_2 responses in *Raphanus raphanistrum* and *Plantago lanceolata*: Assessing the potential for evolutionary change with rising atmospheric CO_2. In Carbon Dioxide, Populations, and Communities (C. Koerner and FA Bazzaz, eds.), Academic Press, New York.

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60 Bazzaz et al., 1996. See Kozlowski TT, Kramer PJ, and Pallardy SG (1991). The Physiological Ecology of Woody Plants, Academic Press, New York. 655 p. for additional references.

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62 Aber et al., 1995; Melillo et al., 1993; Kirschbaum et al., 1995.

63 For a review of how disturbances could increase with climate change in the Pacific Northwest, see Franklin JF, Swanson FJ, Harmon ME, Perry DA, Spies TA, Dale VH, McKee A, Ferrell, WK, Means JE, Gregory SV, Lattin JD, Schowalter TD, and Larsen D (1992). Effects of Global Climatic Change on Forests in Northwestern North America. In Global Warming and Biological Diversity, (RL Peters and TE Lovejoy, eds.) Yale University Press, New Haven, p. 244-257. Many of these same ideas can be applied to the White Mountains, see discussion starting on p.16.

64 Davis, 1985.

65 The application of individual-based, gap-phase succession models, which descend from the JABOWA model, to climate change analysis is reviewed in Review and analysis of JABOWA and related forest models and their use in climate change studies. National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin No. 717, June 1996.

66 For reviews and further information on the relationships between winter thaws, summer droughts and forest decline in general, see Auclair, AND, Eglinton PD and Minnemeyer SL (1997). Principal forest dieback episodes in northern hardwoods: Development of numeric indices of areal extent and severity. Water, Air, and Soil Pollution 93: 175-198 and Auclair AND, Lill JT, and C Revenga (1996). The role of climate variability and global warming in the dieback of northern hardwoods, Water Air, and Soil Pollution 91: 163-186. For a description of dieback and decline disease in North American forests in general, see Manion PD and Lachance D (eds.) "Forest Decline Concepts" (1992). American Phytopathological Society Press, St. Paul, MN

and Little CE "The Dying of Trees: The Pandemic in America's Forests", 1995 Penguin Books, New York.
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72 Dr. Allan Auclair, Science and Policy Associates, Inc., Washington, DC., unpublished data.
73 Nicholls N, Gruza GV, Jouzel J, Karl TR, Ogallo LA, and Parker DE (1995). Observed Climate Variability and Change. In Climate Change 1995: The Science of Climate Change. (Eds. JT Houghton, LG Meira Filho, BA Calander, N Harris, A Kattenberg and K Maskell) Cambridge University Press, Cambridge. p.137-192.
74 Ecosystems in the Northeast exposed to a variety of air pollutants that affect basic soil characteristics like pH and nutrient levels, lead to increased levels of toxic metals in the soil (e.g., aluminum) as well as directly damaging plant structures like leaves and roots. Many studies have been done on how each individual pollutant affects the biotic resource. However, the interactive effect of these pollutants in combination with climate change is only beginning to be studied. The accumulation of stresses that the combination of air pollution and climate change represents could lead to severe declines in forest ecosystems. For more information, see Bormann FH (1985). Air pollution and forests: An ecosystem perspective, Bioscience 35:434-441 and Aber JD, Driscoll C, Federer CA, Lathrop R, Lovett G, Melillo JM, Steudler P and Vogelmann J (1993). A strategy for the regional analysis of the effects of physical and chemical change on biogeochemical cycles in northeastern (U.S.) forests, Ecological Modelling 67:37-47. Researchers at the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire including Dr. John Aber, Dr. Scott Ollinger and others are currently refining the ecosystem model PnET described above (see page 12) to include the multiple interactions that may occur between atmospheric deposition, air pollution, ozone and climate change in the northeastern United States.
75 Houston, DR (1981) Stress-triggered tree diseases: The diebacks and declines. NF-INF-41-81. USDA, Forest Service, Broomall, Penn. USA.
76 Likens et al., 1996.
77 Sugar maple decline is an excellent example of the interaction between pollutants, soil nutrient levels, climate and insects and disease. For examples, see Adams CM and Hutchinson TC, (1992). Fine root growth and chemical composition in declining Central Ontario sugar maple stands. Can J For Res 22: 1489-1503; Bernier B, D Pare', and M Brazeau (1989). Natural stresses, nutrient imbalances and forest decline in Southeastern Quebec, Water, Air and Soil Pollution 48: 239-250, 1989 and Auclair et al., 1997; Auclair et al., 1996; as well as the discussion of sugar maple decline in this report (page 14).
78 These comments on disturbance refer to forests in general. More information on disturbance and forests can be found in Waring RH and Schlesinger WH (1985). Forest Ecosystems: Concepts and Management Academic Press, Orlando, FL, 340p.
79 Hamburg, SP (1984). Organic matter and nitrogen accumulation during 70 years of old-field succession in central New Hampshire. Ph.D. Dissertation, Yale University, New Haven, CT, 250pp.
80 New England's landscape is highly dissected and fragmented due to repeated cycles of clearing for agricultural and forestry uses. However, since much of the area has regrown forests, this fragmentation is not always readily apparent. It has been hypothesized that fragmentation will limit the ability of species to respond to climate change by migration (for example, see Huntley B (1991). How plants respond to climate change: Migration rate, individualism and the consequences for plant communities. Annals of Botany 67: 15-22). The full significance of historical fragmentation of the landscape in places like New England as it might impact migration of species due to climate change needs to be worked out in more detail.
81 Kircher, JC (1988). A Field Guide to Eastern Forests. Houghton Mifflin Company, Boston.
82 Increased fire frequency for this region has been predicted by the MAPSS model (Neilson, 1995) and is discussed in general terms in Kirschbaum et al., 1995, the forests chapter of the IPCC, 1995 report.
83 Storm frequency is predicted to increase in some climate models (IPCC, 1995). However whether this finding can be specifically applied to New England or the White Mountains in particular is not yet known. Climate modeling that would include enough topographic and site specific details to answer this question has not yet been developed for this region. There is also little consensus on whether or not hurricanes will increase in frequency or severity with climate change. Research is actively being pursued to answer these questions.
84 Bormann and Likens, 1979.
85 IPCC, 1995.
86 See Karl et al., (1995), for an analysis of how the frequency of intense downpours has increased in the last century for the northeastern United States.
87 Associated Press, October, 1996.
88 For a general discussion of how pests and pathogen outbreaks could increase with global warming, see Dobson A and Carper R (1992). Global Warming and Potential Changes in Host-parasite and Disease-Vector Relationships. In Global Warming and Biological Diversity, (RL Peters and TE Lovejoy, eds.) Yale University Press, New Haven. p. 201-217.
89 McClure MS (1995). Biology of *Adelges tsugae* and its potential for spread in the northeastern United States. Proceedings of the First Hemlock Woolly Adelgid Review, (SM Salom, TC Tigner, and RC Reardon, eds.), Charlottesville, Virginia, October 12, 1995, USDA Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia, p. 16-25. Hemlock wooly adelgid, an introduced insect species that preys on hemlock, suffered high mortality (>90%) during the severe winter of 1993-1994 in Connecticut. It is probable that the strain of hemlock wooly adelgid found in eastern North America today derives from a less cold-hardy stock than is found in general in its native Japan. For this reason, this adelgid may eventually develop sufficient cold hardiness to expand its distribution northward despite low winter temperatures. The rate of that spread could be hastened by warmer, less severe winters due to climate change.
90 For a discussion of how drought could lead to pest outbreaks, see Mattson WJ and Haack RA (1987). The role of drought in outbreaks of plant-eating insects. Bioscience 37:110-118. For a general discussion of how global warming could affect plant-parasite interactions, see Rubinstein DI (1992). The greenhouse effect and changes in animal behavior: effects on social structure and life-history strategies. In Peters and Lovejoy, 1992.
91 Goss, LE (1995). Fiscal Year 1994 Travel Economics Report, The Institute for New Hampshire Studies, Plymouth State College.
92 ibid
93 U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census (1993), 1991 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, U.S. Government Printing Office, Washington, DC, 1993.
94 New Hampshire Department of Resources and Economic Development (1993). The New Hampshire Ski Industry 1992-1993, Its Contribution to the State's Economy, prepared by The Institute for New Hampshire Studies, Plymouth State College, (1993).
95 U.S. Census Bureau, Census of Housing, "Vacation Homes," (1997).
96 Dr. Laurence Goss, personal communication, Institute for New Hampshire Studies, Plymouth State College
97 For general descriptions of fall coloring and leaf abscission, see Raven PH, Evert RF, and Curties H (1981). The Biology of Plants, 3rd Edition, Worth Publishers, Inc., New York.686p. and Kozlowski et al., 1991.
98 Kozlowski et al., 1991.
99 The drought tolerance characteristics of these trees are described in Burns RM and Honkala BH, Tech. Coords. (1990). Silvics of North America, Volume 2. Hardwoods Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C. 877p.
100 For a review, see Kozlowski et al., 1991
101 See p. 10 in this report and Kirschbaum et al., 1995.
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103 Ibid.
104 Ibid.
105 Predictions are for central North America, see Kattenberg et al., 1995.
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110 The main factors influencing fish species distribution in streams in general are stream temperature, gradient, stream order (size of stream), and flow rate. See Moyle PB and JJ Cech Jr, (1996). Fishes, An Introduction to Ichthyology, Third Edition, Prentice-Hall, New Jersey.
111 See Sternberg (1996) Freshwater Gamefish of North America Cy Decosse Inc. Minnetonka, MN 160pp. for description of trout habitat requirements.
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113 U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census (1993). 1991 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, U.S. Government Printing Office, Washington, DC.
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116 Low flows and their impact to trout populations in New England are described in U.S. Department of Agriculture, Forest Service, Final Environmental Impact Statement, Loon Mountain Ski Area, South Mountain Expansion Project, FS-6200-28 (7-82), October, 1992.
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122 Regier H A and J D Meisner, (1990). Anticipated effects of climate change on freshwater fishes and their habitat, Fisheries, 15(6): 10-15.
123 Value is defined as "... the dollar amount individuals are willing to pay over and above their current expenditures to ensure the continued availability of the opportunity to use recreational fishing resources" and were calculated as part of an empirical review of recreational fishing day values. (EPA, 1995; p. 3-16).
124 EPA 1995. This particular result used the GFDL Transient 2050 climate model. The recreational fishing model assumes that the loss in cold-water acreage translates directly into an equal expansion of cool (e.g., Northern Pike, Walleye, Yellow Perch), warm (e.g., Bass Crappie), and rough guild (e.g., carp, catfish, suckers) fishing opportunities. An equal exchange of habitats, however, is unlikely, because of other limiting factors such as stream velocity as described in the text. For the entire set of 6 climate models that were used as inputs to the recreational fishing model in the report, the change in economic value nationally ranged from a gain of $80 million to a loss of $320 million. The recreational fishing model includes assumptions about fishing-day values, fish thermal tolerance limits, warm-water fishing behavior, delineation of fish habitats, substitutability of cool- or warm-water habitat for cold-water habitat, and runoff. While these assumptions were considered by the authors to be their most conservative and best estimates, a sensitivity analysis of how varying these assumptions would affect the model output resulted in a wide range of national economic losses ($1.6 billion) or benefits ($1.0 billion). Incorporating additional potential runoff changes alone, such as the potential for low stream flows during the summer as a result of lowered precipitation and increased evaporation, resulted in an increase in the estimated losses by $0.4 to $1.0 billion per year.
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