CHAPTER
Four

Ecological Vulnerability to Climate Change: Terrestrial Ecosystems

Forested Landscapes

The distribution of forest types in the Great Lakes region is controlled by a pattern of increasing rainfall as one moves from west to east, and colder temperature as one moves south to north. These climatic gradients gave rise to forests dominated by oaks and hickories in the southern Great Lakes region, northern hardwood forests composed of sugar maple, American beech, and American basswood farther north, and boreal forests dominated by white spruce and balsam fir in the northernmost portion of the region (Figure 26). In the drier western part of the region, closed canopy forests give way to scattered savannas consisting of bur oak and mixed prairie grasses.

Human land-use decisions have reshaped much of what climate, soils, and geology wrought. On drought-prone soils, frequent wildfires once maintained coniferous forests composed of white and red pine in the northern portion of the region. These were largely eliminated by intensive timber harvests during the late 1800s. In the southern Great Lakes region, large areas of fertile soils once in forest cover have been in agricultural production for almost 150 years. Major areas still dominated by forests lie mostly in the northern parts of Michigan, Minnesota, and Wisconsin and in Ontario, where climatic and soil conditions are less favorable for agriculture. Forests currently occupy 36 percent of the total land area in the US Great Lakes states and 63 percent of the land area in Ontario.[129]

Distribution and Productivity

Tree species have been migrating across the region in response to climate change since the end of the last ice age some 10,000 years ago.[130] The pace of climate change will accelerate over the next century, however, and the ability of forest trees to migrate in response will depend not only on their own traits (such as whether their seeds are dispersed on the wind or by animals) and natural geographic barriers (such as the Great Lakes), but also on human land-use decisions. Geographic variation in soil moisture and texture will also put strong constraints on the movement of plant species and the composition of future forests in any given location.

FIGURE 26
The Northern Forests

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Warmer temperatures and a longer growing season are likely to result in the northward movement of many forest species and a general decline in the extent of boreal forests in the region.[131] Northern conifers such as white pine and hemlock are likely to be restricted to isolated populations or lost completely from southern Illinois, Indiana, and Ohio.[132] Tree and prairie grass species in the western part of the region are likely to move eastward, especially if warmer temperatures result in more frequent drying out of soils or even droughts in their current range.[133]

Prior to widespread fire-suppression efforts during the twentieth century, fire was an important agent shaping the composition and distribution of forests in the region.[134] Fires swept through the northern forests every 10 to 50 years, maintaining nearly 75 percent of the land area as young, recently burned forest stands. Surface fires that consumed dead leaves and twigs lying on the ground were common in hardwood forests growing on moist soils, whereas severe canopy-consuming fire often destroyed red and jack pine forest on dry, sandy soil.[135] Fire history studies have shown that over the past 750 years, fire was more frequent during periods of warm temperatures and low precipitation,[136] which suggests forest fire frequency is likely to increase as the climate turns warmer and summers become drier. In fact, as a result of the projected higher temperatures and lower summer precipitation, models suggest decreased soil moisture during summer and autumn,* which would not only increase the fire risk but also limit forest growth in drier areas for more weeks per summer. In wetter areas, forest growth is rarely water limited. The response to changing soil moisture will also interact with changes in fire frequency, since forests in drier areas are more fire-prone.

Forest growth could potentially get a boost from the rise in atmospheric CO_2.

Forest growth could potentially get a boost from the rise in atmospheric CO_2 that is helping to drive climate change. CO_2 acts as a plant fertilizer, and native trees grown experimentally in elevated CO_2 have shown increased growth. Trembling aspen, an ecologically and economically important tree in the region, could increase its growth 16 to 32 percent as CO_2 levels rise. Aspen forests on fertile soil will experience greater growth enhancement than those on nutrient-poor soil.[137] Elevated CO_2 could also accelerate the pace of forest succession, speeding up the rate at which "pioneer species" such as aspen (which colonize sites following disturbances such as timber harvesting or fire) give way to species such as maple that establish in the shade of the pioneering trees. Maple trees grown under elevated CO_2 become more tolerant of shade and increase their growth rate. Faster forest development could shorten the harvest rotation for aspen managed for fiber production in the northern parts of the region.

Another factor that could boost forest growth and productivity is the availability of nitrogen, a key plant nutrient. Human activities, including the fossil fuel burning that is helping to drive climate change, have almost doubled the amount of nitrogen entering forests via rain, snow, and dry airborne particles. Much of the excess nitrogen falling on forests is deposited as nitrate, which is rapidly taken up by soil microorganisms and eventually made available to fertilize plant growth.[138] In this way, forests function as "living filters," preventing nitrate from leaching into groundwater, streams, and lakes where it becomes a pollutant. This filtering capacity may be exceeded in the long term, but in the short term, extra nitrogen from the atmosphere could enhance the ability of forest trees to grow faster in response to rising atmospheric CO_2.

Ozone, however, may counter the growth-enhancing potential of both CO_2 and nitrogen. Ground-level concentrations of ozone are increasing, especially downwind of major urban areas in the region. Elevated ozone concentrations can damage tree leaves, damping growth and rendering trees more vulnerable to insect pests and diseases. Susceptibility to ozone damage varies among tree species and also among different individuals within a species.[139] Experiments that exposed young aspen, paper birch, and sugar maple to both CO_2 and ozone indicate that relatively small increases in ozone can eliminate the growth-enhancing effects of elevated CO_2.

No one can yet predict exactly how changes in temperature, moisture, fire, CO_2, nitrogen, and ozone will interact over the coming decades to alter the

* For additional climate modeling results and other technical information, see www.ucsusa.org/greatlakes.

growth and distribution of forests. The uncertainty stems in part from the centuries-long lifespan of forest trees. Even multiyear experiments subjecting saplings to enhanced levels of CO_2 cannot determine, for example, whether the faster growth means trees will actually grow larger or will simply reach the same size faster than trees growing at current CO_2 levels. And no studies have attempted to look at all the interacting human and environmental factors that will shape the fate of future forests in the Great Lakes region.

Impacts on Forest Insects

Insects have the potential to shift both the magnitude and direction of plant responses to climate change. Through their roles as herbivores, pollinators, and decomposers, insects influence primary production, community composition, nutrient cycling, and successional processes in the forests. The fate of any particular insect species in a changed climate is difficult to predict, yet some general trends can be foreseen.

The northern limit of some devastating forest pests such as the gypsy moth is currently determined by cold winter temperatures, and these insects will almost certainly become more widely established throughout the region in a warmer climate (Figure 27).[140] Insect ranges may also shift as their host trees migrate in response to climate. For example, the range of the eastern tiger swallowtail is likely to expand northward, coincident with expansion of the range of its preferred host, the tulip tree. Simultaneously, the range of the Canadian tiger swallowtail will retract northward, as its preferred host, aspen, disappears from the southern Great Lakes region (Figure 28).

Climatic changes that alter the synchrony between key insects, desirable and undesirable, and their host plants could markedly affect forest ecosystems. Several of the most damaging pests in the region such as the forest tent caterpillar, gypsy moth, and spruce budworm are spring-feeding insects whose emergence is closely synchronized with the bud-break of their hosts. Although both insect emergence and bud-break are controlled by temperature, it is unclear whether climate warming will alter both processes at the same rate. Asynchrony by as little as a week could markedly alter insect fitness and the potential for outbreaks. The activity of insect predators and parasitoids that prey on insect pests is also controlled by temperature, and how warmer climates will alter their effectiveness as natural enemies is virtually unknown. Pollination services are another critical insect-plant interaction that could be disrupted if climate change decouples the timing of flowering and pollinator activity.

In addition to climate changes, both elevated atmospheric CO_2 and elevated ozone are likely to affect insects via changes in host quality. The leaves of plants grown under enriched CO_2 typically are reduced in food value, that is, lower in protein and higher in unpalatable compounds such as tannins.[141] Leaf-chewing insects fed this material generally eat more to compensate for low protein levels. They also experience slower development and reduced growth efficiency.[142] Whether this phenomenon will result in greater defoliation of forests is unknown because, although individual insects may eat more, overall insect population densities might decline. Elevated ozone concentrations in the lower atmosphere can also change plant chemistry. In trembling aspen, ozone exposure compromises production of the major chemical defense compounds, leading to improved performance by forest tent caterpillars.[143]

FIGURE 27
Forest Pests in a Changing Climate

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FIGURE 28
Range Shifts of the Canadian Tiger Swallowtail

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Despite numerous uncertainties, it is clear that coming changes will not affect all plants, insects, and their natural enemies uniformly. The fitness of some will improve, while that of others will deteriorate. Shifts in insect population and community dynamics will feed back to affect how forests of the region function as responders to, and modulators of, climate change.

Impacts on Wildlife

One important ecological implication of forest change is the possible degradation of migratory corridors for animals. A wide gap of largely agricultural lands exists between the extensive tropical forests of Central and South America and forests in the northern Great Lakes where many migratory songbirds such as scarlet tanagers, warblers, thrushes, flycatchers, and vireos breed. This gap is actually wider than the portion of the Gulf of Mexico that many of these tropical migrants must cross. The networks of wooded streams, woodlots, and even urban forests that dot the agricultural portions of this gap are critical stopover and refueling sites for the migrants.[144] Climate-driven shifts in the timing of tree leaf-out, seed production, and insect emergence, however, may throw these wooded remnants out of sync with the birds' arrival.[145]

> Fragmentation and the disruption caused by climate change will increase the opportunities for exotic species to invade forests, further stressing native species.

Currently, for instance, migrating songbirds gather in oak trees in large numbers during spring migration to consume caterpillars that attack the oaks during leaf-out, a situation mutually beneficial to the trees and the birds.[146] But leaf-out of trees and hatching of caterpillar eggs is closely tied to temperature and is expected to occur earlier as the climate warms.[147] Because many birds migrate in response to day length rather than temperature, some songbirds may arrive from the tropics well after the spring flush of insects that accompanies leaf-out.[148] The same phenomenon may apply to the flush of spring insects coming out of wetlands that are vital to many migratory songbirds. Unlike migrants, however, some year-round resident birds may benefit from warming, a phenomenon that could further stress migratory birds (see box, p.30).

FIGURE 29
Virginia Possum's Range Expanding North

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Popular gamebirds such as ruffed grouse, which are most abundant in aspen forests, might be especially likely to shift their ranges to the north. Indeed, the failure of efforts to reintroduce ruffed grouse to parts of their historical range in Illinois might be partly a result of changing forest conditions caused by climate change as well as human land use.

Climate warming may also benefit some resident mammals such as white-tailed deer, which are already experiencing record high populations in the region and are severely altering forest growth with their browsing. Reduced winter mortality during milder winters might exacerbate this damage to forests. Moose, which are already near their southern geographic limit in the region, could be negatively impacted both by warming and by the increasing density of deer.[149] Deer carry three parasites—brainworm, liver fluke, and winter tick—that severely stress moose.

Reduced winter mortality of omnivorous mammals such as raccoons, possums, and skunks could increase their overall abundance, potentially increasing predation on ground-nesting songbirds and other vulnerable prey (Figure 29).

The benefits of warming for some resident mammals and birds could be countered by potential changes in the dynamics of wildlife diseases or increased winter survival of pathogens and insect vectors. Such effects would be most pronounced in northern species that have not been exposed to or evolved defenses against diseases from warmer latitudes.

Climate change will also interact with forest fragmentation, particularly in heavily agricultural areas, to create greater stress on many breeding birds and some reptiles and amphibians. The impact will be most severe on relatively immobile species, restricting their ability to move northward to colonize newly suitable patches or escape newly inhospitable climates. On the other hand, some predators that already thrive in fragmented habitats will benefit from warming. Rat snakes, for example, are more active in warmer temperatures in fragmented habitats where they are exposed directly to sunlight on the forest edge.[150] Some of these predators will also move north, increasing the stresses on nesting birds. Snakes are dominant nest predators south of the Corn Belt, but are actually an endangered species in Canada where they depend heavily upon edge habitats.

Fragmentation and the disruption caused by climate change will also increase the opportunities for non-native species to invade forests, putting further pressures on native species.

Agricultural Landscapes

The six Great Lakes states contain 100 million acres of farmland and send more than $40 billion (US) in products to market. Agricultural production from 14 million acres of farmland in Ontario is valued at $10 billion (Cdn). In general, livestock is more important in the northern areas (Minnesota, Wisconsin, western Ontario) while row crops dominate the southern areas. All of the Great Lakes states rank in the top 20 for the value of dairy products and crops sold nationally (Figure 30). The region also ranks high in production of horticultural crops and fresh market products, from vegetables to fruit.[151]

Crop production in the region is primarily rainfed, and weather is the most important uncontrolled factor influencing crop production. Production can be harmed by heat stress, pests, ozone, extreme weather events such as rains that delay planting or harvest, and below-normal precipitation, especially during critical stages of plant growth (see Figure 15, p.19).[152] Historical influences of weather on yields are difficult to separate from the influences of technological and cultural improvements, which have dramatically increased yields over the past century[153] but have also led to a transformation and in some cases impoverishment of the Great Lakes regional landscape.

Climate Impacts on Crops

Most predictions from large-scale simulations suggest that while climate change is likely to shift crop production patterns, the region's agricultural capacity is unlikely to be seriously disrupted over the next century.[154] Indeed, yield increases of 15 to 20 percent for many crops have been projected based on earlier climate models projecting less warming, although these studies concluded that tropical or warm-season crops such as corn may increase less than soybeans and wheat. Another recent analysis suggests that soybean biomass could increase by 40 percent and soybean yield by 24 percent.[155] Such predictions remain highly uncertain, however, because the strength and even direction of crop responses can shift with different climate change scenarios.[156] Unless temperatures actually warm beyond crop growth thresholds, factors other than climate change will have as great or greater influence on trends in agriculture. These factors include regional population growth, access to resources including emerging technology, and market fluctuations.[157]

FIGURE 30
Mixed Impacts for Agriculture

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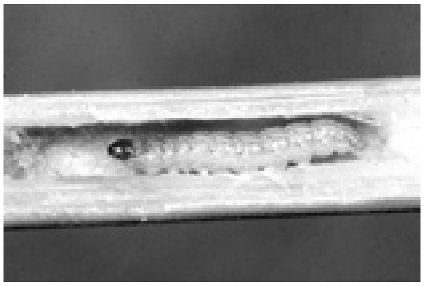
Producers may take no comfort in predictions for "average" responses of crop yields to various climate change factors. Averages mask site-to-site and increasing year-to-year variability in yield, which at the farm level translates to higher risk. One study of impacts of climate variability on farm-level risk of crop failure in Illinois and Wisconsin found, not surprisingly, that risk exposure was greater for smaller farms and varied regionally and among crops.[158] Such impacts on variability and risk are likely to reinforce the trend toward increasing farm size and industrialization of agriculture in the region.

Models run at smaller scales consistently show that the effects of changing climate will vary across the Great Lakes region. Optimal weather conditions will shift northward and eastward, typically bringing the greatest benefits to Michigan, Minnesota, Wisconsin, and eastern Ontario.[159] Shifts in the distribution of agriculture may be constrained in northern areas by thin and acidic soils[160] (see Figure 2, p.8). If more intensive production moves upward from the southern edge of the Great Lakes region onto shallower,

FIGURE 31
Climate Change and Agricultural Pests



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coarser textured soils in the northern areas, chemicals and nutrients used to increase soil fertility may increasingly run off into aquatic systems. Agriculture is currently a chief source for chemical contamination of ground and surface waters, but there has been little investigation of how redistribution of agriculture in a changing climate may interact with this problem.

One recent study projected increases in production thanks to a longer growing season and warmer temperatures,[161] but that study relied on a model that predicts precipitation trends that are much more favorable for crop production than this report assumes. Yield trends are likely to fall short of those predictions if summer rainfall decreases, as suggested by the climate scenarios used in this report (see Figures 12 and 13, p.18). These scenarios project wetter periods occurring during times that could delay harvest or planting, and dry spells during times when crops demand water. As models improve and include factors such as extreme weather events or the influence of pests, they are likely to produce less favorable outcomes for agriculture than have been predicted to date.

After factoring in extreme weather events or the influence of pests, the picture for agriculture is less favorable than previous predictions suggested.

The complexity of agricultural responses to climate change is highlighted by an integrated assessment that focused on five upper Midwest states: Illinois, Indiana, Michigan, Ohio, and Wisconsin.[162] Trends in southern areas of Ontario would be expected to resemble those projected for Michigan. The assessment predicted mean increases in corn yield of 5 percent, but the range of both increases in some northern areas (+0.1 to + 45 percent) and decreases in southern areas (0 to – 40 percent) was large. The largest corn-yield decreases were projected for western Illinois.[163] In addition, the assessment predicted that CO_2 fertilization and earlier planting dates could increase soybean yield up to 120 percent above current levels in the central and northern portions of the region. In the southern areas, comparatively small yield increases (0.1 to 20 percent) or small decreases (–0.1 to –25 percent) were predicted. Wheat yields may also increase approximately 20 percent as a result of CO_2 fertilization; however, increases resulting from earlier planting dates might be limited because they overlap the growing season of a previous crop.

CO_2 fertilization may also influence crop yield in indirect ways. Initial results from a large-scale experiment that began in Champaign, Illinois, in 2001 showed, as expected, that elevated CO_2 enhanced soybean yields. The results also indicated that elevated CO_2 increased the water use efficiency of the soybean plants, a response that has the potential to reduce crop water requirements and reduce the flux of water into the atmosphere.

Ozone concentrations can counter positive trends in crop yields just as in forest productivity. In addition to urban sources of ozone in the region, agricultural application of fertilizers can cause local peaks in ozone levels, and warmer temperatures can also increase ozone formation. Already, regional ozone concentrations frequently reach levels that damage crops,[164] and ozone exposure is credited with causing, alone or in combination with other pollutants, about 90 percent of the air pollution–based crop losses.[165] Ozone damage is expected to cause localized areas of losses in soybean yields of 11 to 20 percent in the Mississippi and Ohio valleys.[166] Similar losses are projected for horticultural crops, which are at least as sensitive to ozone damage as soybeans.

Impacts on Agricultural Pests

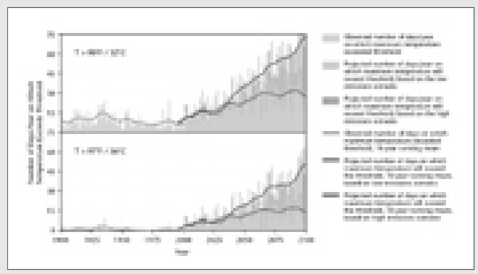
Warming temperatures may influence pest and disease incidence in several ways. First, warmer and shorter winters will allow more southerly pests such as corn earworms and fall armyworms to expand their range northward. Indeed, such a shift already appears to be happening with bean leaf beetles, which

Extreme Events, Public Health, and the Human Environment

Extreme events such as heavy downpours, floods, heat waves, droughts, tornadoes, and snowstorms are expected to play a growing role in a warmer world. This will put increasing burdens on emergency management, public works, and health care services and exact a growing financial toll from governments, businesses, and homeowners. Illinois has experienced a stark preview of this future scenario during the past 15 years with a severe drought in 1988, Mississippi River flooding in 1993, a 1995 heat wave, a severe rainstorm in Chicago in 1996, a 1996 heat wave, a 1999 windstorm in Bloomington, another Mississippi River flood in 2002, and numerous tornadoes and severe storms.[40]

The disruptions and losses society faces were dramatically demonstrated during the record-breaking 24-hour rainstorm that occurred on July 17–18, 1996, in south Chicago. Chicago and 21 suburbs experienced flash flooding that broke regional records and killed six people, damaged 35,000 homes, and caused evacuation of more than 4,300 people. Losses and recovery costs reached $645 million (US), making that single storm Illinois' second most costly weather disaster on record after the 1993 Mississippi River flood. In adjacent rural areas, flood damage to crops cost farmers $67 million (US).[167]

FIGURE 32A
Temperature Extremes in the Great Lakes Region



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Other changes that will impact human health and environmental quality are expected to include the following:

An increase in extreme heat and heat waves

The number of hot days is projected to increase in the Great Lakes region through 2100 (Figure 32a), with many years experiencing 40 or more days exceeding 90°F (32°C) by the last few decades of the century. Of greater concern for human health is the projected increase in days reaching 104°F (40°C) or more. In the upper Great Lakes, the impacts are likely to be greatest in urban areas, especially in cities such as such as Toronto or Minneapolis/St. Paul where extremely high temperatures have historically been rare. A recent health impacts study for the Toronto-Niagara region found that the current number of days with maximum temperatures above 86°F (30°C) could double by the 2030s and surpass 50 days by the 2080s. The annual heat-related death rate of 19 per year in Toronto alone could increase 10- to 40-fold, depending on the climate scenarios used.[168] On the other hand, cold-related health risks are likely to decline over time if the frequency of extreme cold weather periods during winters decreases.

A potential boost to air pollution

Higher temperatures may enhance the formation of ozone and also increase demand for electricity for summer air-conditioning, thereby boosting emissions of air pollutants that can exacerbate respiratory disease. Studies using older climate models indicate that weather conditions conducive to high ozone are likely to occur more often by the end of the century.[169] Indeed, the number of hot days conducive to high ozone might increase by 5 to 100 times present levels for Detroit. Newer climate models predict even higher temperatures and thus greater exacerbation of air pollution.

Water quality changes

Climate-related risks to the region's water supply include potential increases in nitrate pollution, nuisance algal blooms, pesticide residues and other toxins stored in lake and river sediments, and the spread of parasitic and pathogenic microorganisms. For example, some waterborne infectious diseases such as *cryptosporidiosis* or giardiasis may become more frequent or widespread if extreme rainstorms occur more often.[170] One of the best known examples of a *cryptosporidium* outbreak occurred in Milwaukee in 1993 after an extended period of rainfall and runoff overwhelmed the city's drinking water purification system and caused 403,000 cases of intestinal illness and 54 deaths.[171] Milwaukee's drinking water originates in Lake Michigan.

FIGURE 32B
Concerns About Insectborne Infectious Diseases

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Potential changes in vectorborne infectious disease risks

The occurrence of many infectious diseases is strongly seasonal, suggesting that climate plays a role in influencing transmission.[172] St. Louis encephalitis outbreaks in the Great Lakes region, for example, have been associated with extended periods of temperatures above 85°F (29°C) and little rainfall.[173] Some vectorborne diseases such as Lyme disease or, more recently, West Nile encephalitis have expanded widely across the region. While this spread is attributed largely to land use changes, future changes in rainfall or temperatures could encourage greater reproduction or survival of the disease vectors, which are ticks and mosquitoes, respectively (Figure 32b).[172]

not only feed on soybeans but also serve as vectors for a virus that causes disease in soybeans. Second, warming will increase the rate of insect development and the number of generations that can be completed each year, contributing to a build-up of pest populations. Extended growing seasons are likely to allow the northward expansion of some pests with multiple generations per year, such as a race of European corn borer now limited to southern Wisconsin and further south (Figure 31, p.62). Increased pests may also drive farmers to use more pesticides or related chemicals, placing an additional burden on water quality.

The decline in the food value of plant leaves under increasing CO_2 will also interact in complex ways with a warming climate to affect both plants and insects. For example, one study found that warming accelerated insect development to such an extent that the larvae could not feed long enough to compensate for the poorer quality of the foliage.[174]

Impacts on Livestock

Climate change will affect livestock production indirectly through influences on forage quantity and quality, and directly through influences on animal physiology or facility requirements. Direct impacts include warmer summer temperatures that suppress appetite and decrease weight gain in animals. For example, a 9°F (5°C) increase in temperature is projected to reduce animal productivity by 10 percent for beef and dairy operations in the southern parts of the United States,[175] although other studies predict only 1 percent losses.[176] Higher temperatures are likely to reduce stocking rates on pastures[177] and can reduce milk quality by reducing forage quality and stressing animals. Any extreme weather events such as heat waves, droughts, and blizzards have severe effects on livestock health, although intensively managed livestock operations are better able to buffer the effects of extreme events.

Negative impacts on forage and grassland productivity and forage quality can result from summer drought stress or extreme winter weather. One study predicts that warmer fall temperatures will reduce fall hardening of forage crops, rendering them less hardy during the winter.[178] Additionally, there will be less protection by snow cover.

FIGURE 33
Climate Change Impacts on the Timber Industry

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Economic Consequences of Climate and Ecological Changes in Terrestrial Systems

Forests and Wildlife

Commercial forestry is a substantial industry in northern parts of the region, and significant forest products industries exist in Ontario and all Great Lakes states except Illinois (Figure 33).[4] Climate warming will drive changes in forest extent and in the types of trees found in various parts of the region. During the transition, however, while trees ill-suited to new climate conditions persist and better-suited species are taking hold, forest productivity and forest industries may suffer.

Changes in the types of trees in the forest may also be jarring to many residents' sense of place. Shifts from boreal fir to hardwood forests in the northern Great Lakes region could occur in the lifetime of current residents, fundamentally changing the character of these locations. While a "sense of place" is felt strongly by many people, it is hard to assign it a dollar value equivalent to dollar values for changes in harvestable timber.

Changes in forest composition and extent will also affect wildlife and the recreational industry that has grown up around harvesting or watching wildlife. Approximately 13 million adults in the Great Lakes states participate in bird watching or other wildlife viewing, and another 3.3 million hunt.[13] Declines in bird species would have direct economic consequences in terms of hunting or bird watching as well as indirect consequences through loss of the birds' services in controlling insects and other pests. The loss of goose hunting from southern Illinois, where more than a million geese once wintered, has seriously affected the economy of one of the poorest regions of that state.

Agriculture

Whether climate change will be economically advantageous or harmful for Great Lakes farmers remains uncertain. Hotter, drier summer conditions with more frequent droughts, as predicted in this report, could disrupt production, although increased CO_2 fertilization could boost yields of some crops. The fate of agricultural production will also depend upon how climate change affects the variability and predictability of weather patterns. Extreme events such as severe storms, late spring or early fall frosts, and drought all depress productivity.

Apart from extreme events, crop farmers can adapt to moderate changes in temperature or precipitation if such changes can be predicted. Knowing that conditions will be warmer and drier, or warmer and wetter, will allow farmers to plant crop varieties better suited to such conditions. If there is greater uncertainty, however, farmers will not be able to choose the right varieties for conditions that actually occur, leading to a much greater risk of loss. Thus the impacts of climate change on annual crops in the Great Lakes region appear to depend more on predictability and variability of weather patterns than the change in overall averages.[179] Greater climate variability is more problematic for perennial crops such as fruit trees and vineyards where adjustments cannot be made as frequently and long-term investments are at risk.

FIGURE 34
Impacts on Summer Recreation

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Climate changes may also affect production costs. If drier summer conditions and increased drought prevail, investments in irrigation may become necessary. Such a shift would impose costs directly on farmers and increase tensions over water allocations. Without irrigation, however, agricultural productivity can drop sharply during drought. For example, a 1988 drought reduced US corn production by 45 percent.[126]

Increased soil erosion and runoff of agricultural wastes are likely if the frequency of flooding increases.[180] Greater erosion would increase off-site costs of sediments, which are already estimated at $98 million (US) for the lake states of Michigan, Minnesota, and Wisconsin and $216 million (US) for the Corn Belt states of Illinois, Indiana, Iowa, Missouri, and Ohio.[181]

Whatever the overall outcome, certain groups may gain at the expense of others. For example, if climate change tends to increase production, resulting price declines may help consumers but hurt producers. Regional producers will do better if climate change lowers productivity elsewhere, resulting in lower supply and higher prices, but does little to change their own productivity. In an era of expanding global trade, however, prices to farmers and costs to consumers in the Great Lakes region may be influenced more by how drought or rain is playing out in crop fields half a world away than by harvests at home.

Recreation and Tourism

Travel and tourism brought in $65 billion (US) in revenue in the Great Lakes states in 1999[10] and $20 billion (Cdn) in Ontario in 2000.[14] The most certain impacts of climate change will be on winter sports activities. Warm winter temperatures and little snow mean red ink for ski areas, or at least increased costs for snowmaking. Communities and businesses dependent on revenues from cross-country or downhill skiing, snowmobiling, or especially ice fishing, could be hard hit. Some of these communities and businesses, however, will make up the loss by expanding warm weather tourism and recreation (Figure 34).