6. Land Ecology

study conducted by

Daniel G. Brown
University of Michigan, Ann Arbor, Michigan

Karen V. Walker, Margaret B. Davis, and Shinya Sugita
University of Minnesota,
Minneapolis-St. Paul, Minnesota

John D. Lindeberg
Center for Environmental Policy, Economics and Science (CEPES), Ann Arbor, Michigan

The natural ecosystems of the Upper Great Lakes region (Michigan, Minnesota and Wisconsin) are characterized by two climate-related gradients. First, there is a southwest to northeast gradient from prairie to forest in Minnesota. The prairie-forest border consists of transitions from short grasses to tall grasses, to oak savanna and forest, which is largely a function of moisture availability. Second, a shift occurs from boreal species (spruce-fir) in the north, to more maple, beech, birch and oak-hickory in the south due to climate and soil gradients. This gradient, occurring in Michigan and Wisconsin, corresponds with a steep south to north land-use gradient from predominantly agriculture to predominantly forest. Figure 6.1 shows most of these features, although some of them are more difficult to identify because of the superimposed land-use (e.g., row crops are planted over areas covered by prairie).

The Upper Great Lakes region had about 42% forest land – more than 52 million acres – in 1992. Moreover, the second and third-growth forests are now maturing, and recent inventories report an increase in the amount of forested land and in stocking on those lands. These forests are immensely important economically for the region. Over 90% of the forest land is used for commercial forestry, and more than half of the commercial forest land is owned by the nonindustrial private sector [6-1]. The forest sector employs over 200,000 people and generates $36.7 billion per year of economic activity ($24 billion per year for forest products alone), which accounts for 3.7% of the total economic activity in the region (Table 6-1) [6-2]. Products include pulp and saw log production, cabinet grade lumber sales and manufacturing, and production of wood products like oriented strand board and specialty items.

In addition to their commercial value, forests contribute greatly to aesthetics, ecosystem biodiversity, quality of life, clean air and water, and reduction of soil erosion in the region. Resi-

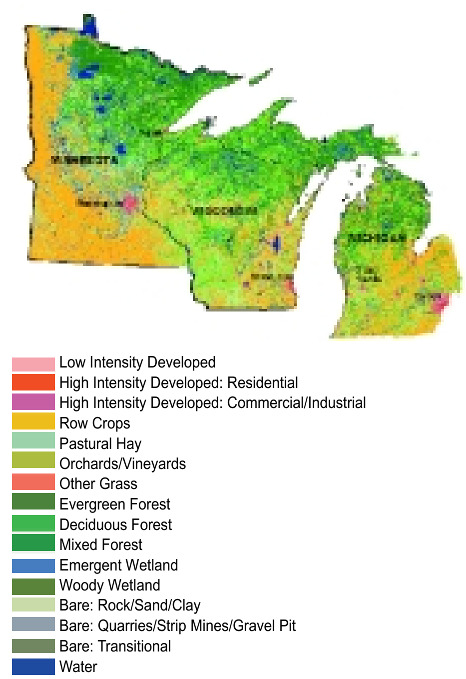

Figure 6.1: Land Cover/Land Use – Midwest Study Area. Source: National Land Cover Data (NLCD) Landsat Thematic Mapper Data, 1988-1994.

dents in the Great Lakes region, like many other Americans, express a desire for these non-commodity values. Places like the Boundary Water Canoe Area in Minnesota, the Upper Peninsula in Michigan, and the Southern Shore of Lake Superior in Wisconsin are frequented by many who appreciate the aesthetic beauty that forests provide. Even the (densely-populated) urban areas have significant tree cover, like the Twin Cities in Minnesota with over 50% tree cover, promoting pride and a sense of well-being to the residents of the region.

The emphasis on non-commodity values often conflicts with the dependence of rural landowners on forests for employment and community development. While both standing volume and demand for forest products continue to increase in the Upper Great Lakes region, the amount of land available for timber production continues to decrease due to conversion to urban and industrial uses, and development of seasonal and retirement homes.

Figure 6.2: Porcupine Mountains escarpment; Lake Superior, Michigan, Source: Michigan Sea Grant Extention, Carol Y. Swinehart.

State	Forested Acres (1,000s)	Portion of Total Land Use (%)	Annual Revenues (1,000s)
Michigan	19,300	53.0%	$ 9,000
Wisconsin	16,000	46.0%	$ 19,700
Minnesota	16,700	33.0%	$ 8,000
Total	52,000	42.7%	$ 36,700

Table 6.1: Forest related economic activity for Great Lakes region. Source: (MI, WI, and MN Departments of Agriculture in conjunction with USDA, 1998).

Current Stresses

The forest resources of the region are under attack, even without the potential for increases in temperatures caused by climate change. Dutch elm disease contributed an almost complete dieoff of this species throughout the region in the 1970s. Foresters, particularly in the urban areas, used this as a lesson to promote diversity among the species that are planted in cities.

Currently, gypsy moth related defoliation exists and is clearly worsening in all parts of the region. State authorities are aggressively seeking to combat this infestation with ground and satellite-based surveys, biological controls, and trapping methods. Without these efforts, the spread of this infestation would be even greater. Oak wilt is another disease that exists in many parts of the region, although it mostly affects the northern portion. State environmental authorities are working with local communities to suppress the spread of infection. Activities like the development of a model ordinance for the purpose of oak wilt control in Wisconsin and the implementation of a federal oak wilt control program in Minnesota have raised the profile of this disease and have been effective at limiting its spread. Other forest-related diseases and pests that are found in the region in non-epidemic numbers include spruce budworm, cankerworms, forest tent caterpillar, white pine blister rust, white pine weevil, basswood thrips, butternut canker, and asian longhorned beetle.

Extreme weather certainly plays a role in regional forest destruction. Severe storms with lightning, high winds, hail, or tornadoes can quickly destroy whole stands of trees. Recently thinned or logged areas and older forests, from which fire has been excluded, are particularly susceptible to destruction in these circumstances. Exceptionally cold or hot (and dry) weather can also retard growth or kill trees depending on the duration and location of such weather.

Land use is also a serious stress. Although farmland decreased by 5% (according to the Census of Agriculture) between 1987-1997 and forest cover increased by 3% (according to the USDA Forest Service) between 1980-1993, these trends are not likely to continue for long. Increasing development, coupled with declining rates of agricultural abandonment, are likely to lead to declines in forest area in the long term [6-3]. Furthermore, large-scale management of forests on private lands is becoming increasingly difficult as ownership is becoming increasingly fragmented into more and smaller parcels [6-4, 6-5]. During the 30 years between 1960 and 1990, average private parcel sizes declined by an average of 1.2% per year across the region. This parcelization process is related to development of recreational and seasonal homes, but does not necessarily result in forest clearing. It does, however, affect the management of forests and, therefore, the ability of foresters to respond to changing climatic conditions.

Figure 6.3: This rural residence in upper Michigan is emblematic of the kind of development underway throughout the region, whether for seasonal, retirement, or permanent homes; photo by: Daniel G. Brown.

Previous Assessments

Previous modeling efforts that have addressed the impacts of climate change on forests in the Great Lakes region [6-6, 6-7, 6-8, 6-9] have consistently projected a northward shift in species ranges. Most of these efforts have shown that species at the southern boundaries of their ranges, like boreal species within the region or northern hardwood species in the southern part of the region, will experience increased mortality and will be eventually replaced by species from communities to the south. Although there is no general agreement on the time that it will take for this replacement to occur (a very important question), the models are in general agreement about the northward shift in ranges. Mortality, disturbance, migration rates, pests, disease, landuse and management will play a critical role in forest health and composition in the coming decades. To date, only a few of the more advanced dynamic or *transient* analyses of climate change and tree species (migration) have been conducted [6-5]. Many more *steady-state* analyses have been performed [6-10, 6-11]. The steady-state analyses, although easier to design and run, simulate current and future climates separated by a sudden and unrealistic jump in CO_2.

The timing of replacement (e.g., the *transient* nature) is critical because dieback of northern species could occur from heat or drought stress, increased winter damage due to diminished dormancy, or increased pest activity, before the southern species are available for replacement. This possibility raises questions about just how susceptible the forests are to increased mortality, how disturbance regimes will be affected by climate change, and how quickly the southern species can migrate. Other questions relate to the possibility that established trees may persist longer than shown in early studies. Confounded with these questions is the possibility that CO_2 enrichment, by improving water use efficiency by trees and increasing productivity, could speed the succession process.

To evaluate long-term productivity, many studies have assumed that atmospheric CO_2 concentrations continue to increase to four times the present value over a period of 200 years. One such study focused on the natural productivity that was simulated at four sites – two in Michigan and one each in Minnesota and Wisconsin – using a forest growth model called FORENA [6-8]. Because of the simulated "dieback phenomenon" the sites experienced a total biomass reduction between 15-30%, with the most dramatic dieback occurring on the Michigan sites. After about 300 years of simulation, and a quadrupling of CO_2 in the atmosphere, biomass returned to original levels or slightly higher. The forest community compositions, however, were modified, generally through replacement of boreal forests by northern hardwoods and southern parts of the northern hardwood forest by eastern deciduous forests.

Current Assessment

The current assessment focused on (1) predicting climate change-induced shifts in equilibrium tree species ranges, (2) comparing effects of land-use and climate change on vegetation community distribution and productivity, and (3) evaluating economic impacts of climate change on the forestry industry.

Predicting Shifts in Tree Species Ranges and Climate Change on Vegetation

Future ranges of ten economically valuable tree species were predicted using the STASH model [6-12]. This model has been used to predict range shifts under future climate conditions of northern Europe [6-13]; this is its first application in North America. The model predicts the geographic location of suitable climate space using climate parameters of known physiological significance. Maximum tolerated summer temperatures was added for this study.

Only the output from the CGCM1 model was used, because cloudiness patterns in the HadCM2 model were found to be inconsistent with other output from that model. Model biases were accounted for by adding the difference between future and current (e.g., 1994-2003) climate model output to current observations [6-14] for each decade examined.

Four categories of tree responses were found. The first category, which includes black cherry and black walnut, is composed of trees that are presently confined to the southern part of the region, and are predicted to expand northward (Figure 6.4). By the end of this century they should be able to grow successfully throughout Northern Minnesota and Michigan. The potential range of black walnut will also expand toward the eastern part of the region along the southern shores of Lakes Erie and Ontario. Prasad and Iverson's [6-11] current range limits (using a different data set) show black cherry as already present in Northern Minnesota. They predict some westward expansion into the prairie for both black cherry and black walnut. However, they do not predict northward expansion and they show black walnut as disappearing from the Illinois region – results quite different from those from the STASH model in this assessment.

The second category, red oak and sugar maple, includes trees whose range limits within the Great Lakes region are not greatly affected, but which may show signs of stress in some areas. It is predicted that red oak will persist within its present range, expanding a few tens of kilometers westward into present day prairie. Toward the end of the 21st century warm conditions in summer will begin to stress this species in the southern part of the region. Soil moisture deficits near the limit for this species will stress populations in the lower peninsula of Michigan throughout the century.

Sugar maple will also be stressed by limiting soil moisture in Lower Michigan. However, in the last decade of the 21st century, it is predicted that sugar maple will begin to grow into regions of Minnesota that were formerly prairie. In contrast, Prasad and Iverson [6-11] predict a strong limitation or elimination of this species throughout the region. Only their predictions using GISS show any sugar maple persisting in the Great Lakes region (in Northern Minnesota). Davis and Zabinski [6-9] pre-

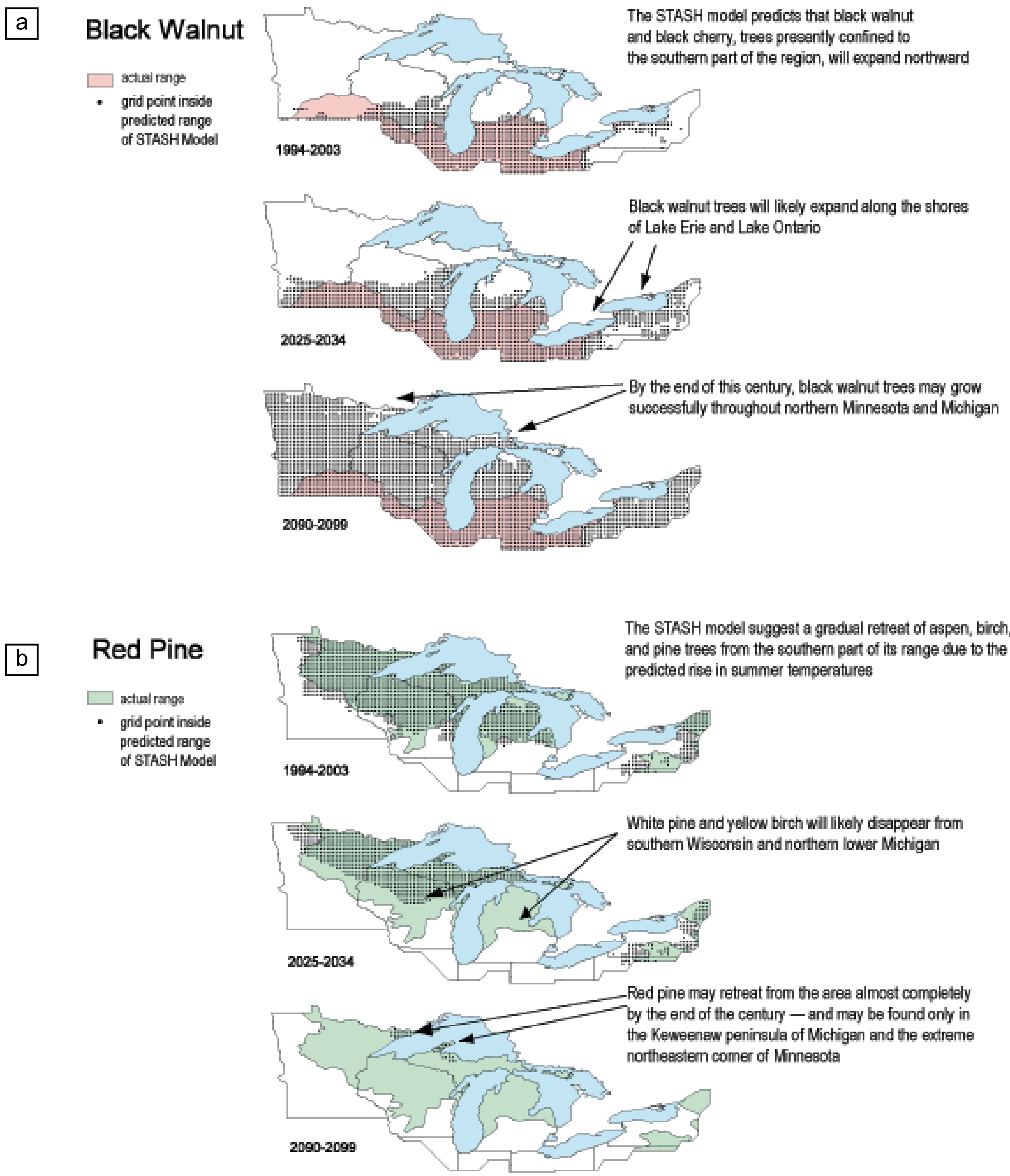

Figure 6.4: Actual (Little, 1971) and predicted (STASH plus the highest tolerated temperature of the warmest month) ranges of a) black walnut and b) red pine in the Great Lakes region.

dicted a marked retreat to northeastern Canada for sugar maple, given the dry central continent predicted by the GFDL model, but persistence within the Great Lakes region rather similar to the present prediction using output from the GISS model.

The third category is composed of species that are predicted to retreat gradually from the southern part of their ranges in the Great Lakes region due to the predicted rise in summer temperatures. Some of the most important timber trees are included in this category: quaking aspen, yellow birch, jack pine, red pine, and white pine (Figure 6.5). By 2099, aspen is predicted to grow only in northernmost Minnesota, Wisconsin, and Michigan, and in the mountainous region of New York and Pennsylvania. White pine and yellow birch will likely disappear from the south, but at the end of the 21st century they should still be able to grow in Northern Minnesota and the Upper Peninsula of Michigan. Jack pine and red pine are predicted to retreat from the area almost completely. By 2099 the only suitable habitats within the region will be on the Keweenaw peninsula of Michigan and the extreme northeastern corner of Minnesota. Similar patterns are shown by Prasad and Iverson [6-11] for red pine, white pine, aspen and yellow birch, although the five climate models differ in their predictions of how dramatic the retreats will be. Current predictions for yellow birch show a greater retreat from the region than the early predictions by Davis and Zabinski using the GISS model [6-9].

The fourth category includes only beech. The results from the current study suggest that this tree may expand westward. Davis and Zabinski [6-9] showed beech retreating from its western limit and moving northward under the GISS climate scenario; under the GFDL climate scenario there was a much larger range movement in the same general direction. Prasad and Iverson [6-11] predicted complete elimination of beech from the Great Lakes region. All of the above studies have had difficulty specifying the climate parameters that correspond to the present range of beech. This may explain why results differ so widely, and adds considerable uncertainty to future predictions.

Decadal maps (not shown) indicate a "flickering" of range limits of several species in lower Michigan from one decade to the next. Soil moisture in this region hovers around the limits for white pine, red pine, yellow birch, sugar maple, black cherry, red oak, and beech throughout the 21st century. Favorable habitat is predicted in lower Michigan for sugar maple, black cherry, red oak, and beech at the end of the century, but these species are predicted to be able to grow there in some decades and not in others. White pine, red pine, and yellow birch display this flickering pattern before disappearing altogether due to warm summer temperatures. "Flickering" trees may survive in favorable habitats (perhaps fine-grained soils) and be exposed to moisture stress in less suitable habitats. Stressed trees will doubtless be very susceptible to insect attack, disease, and disturbance.

Comparing Effects of Landuse and Climate Change on Vegetation

With recent exceptions [6-15], almost none of the work on evaluating the impacts of climate change on natural ecosystems considers the effects of land management. For example, although the region contains significant forest area, about 40% of the land is used for agriculture and much of the forest area is used in some way for forestry. The assessment models are unlikely to capture either the full range of possibilities available in a managed landscape for responding to or mitigating climate change impacts, or the interactions between management and succession. Furthermore, land management activities can modify such ecologically important variables as seed sources and the introduction of exotic species (e.g., gypsy moth and asian longhorn beetle).

The distribution of vegetation communities is summarized in the current assessment [6-16], but in a manner that accounts for the current landuse patterns. This work represents an important attempt to consider land management in the evaluation of potential impacts of climate change on terrestrial ecosystems. Two types of results are presented: (1) changes in the prevalence of seven natural vegetation types as a result of contemporary landuse and under climate change scenarios; and (2) changes in net primary productivity (NPP) in these ecosystems as a result of landuse and climate change.

Changing Vegetation

The influences of contemporary landuses and various climate change scenarios on the composition of the region in terms of vegetation types are shown in Figure 6.5. The long and short grass prairies provide important habitat for a variety of species that have been driven out by conversion to agricultural uses. According to this analysis, about only 1% grassland remains in a natural state due to the agricultural activities on those lands. The areas of temperate deciduous forest and temperate deciduous savanna are similarly affected by the presence of agriculture (only 24% and 31% remain natural, respectively). The vegetation type least affected by current landuse is boreal coniferous forest, which is also the rarest in the region.

Static type vegetation models predict the disappearance of the boreal forest from the region under doubled atomospheric $C0_2$ concentrations. Figure 6.5 shows a consistent and substantial reduction in the amount of area covered by both the temperate continental coniferous forest and cool temperate mixed forest types. This suggests that the northern hardwood forests that sustain the regions with the forest products industry, are projected to undergo substantial conversion to temperate deciduous forest and temperate deciduous savannas. The results for the grasslands were mixed, depending on the moisture projections in the climate scenarios and the assumptions about water use in vegetation models. The fact is, however, that very little natural grassland remains and the fate of the grasslands has more to do with agricultural policies and economic conditions than with climate.

Given the substantial projected expansion of the temperate deciduous forests and savannas (oak and hickory are dominant) it is important to consider two limiting factors. First, between two-thirds and three-quarters of these two communities are under active human management for agriculture and/or development. This may affect the availability of seed for sources and, therefore, delay the northward migration of the species

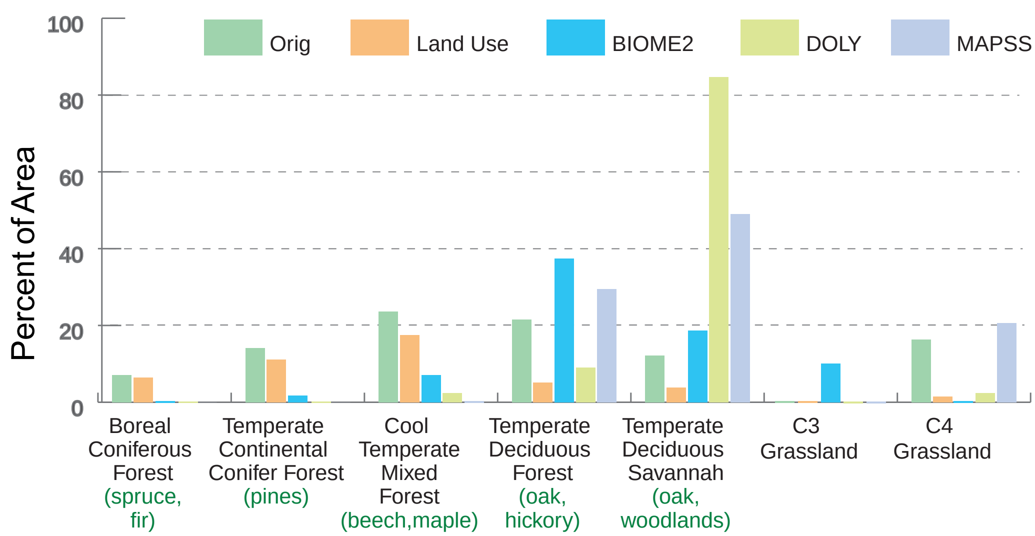

Figure 6.5: The influence of contemporary land use and climate change on the vegetation in the Great Lakes region. The first bar in each group represents the land cover distribution that would exist currently in the absence of any land use. The second bar represents the composition of the region accounting for "non-natural" land uses. The last three bars represent the estimated compositions of the region using three different vegetation models under the climate scenarios (not accounting for land use).

northward. This delay may contribute to the "dieback phenomenon" as communities make the transition from one type to another. Second, the northern forests are strongly influenced not only by climate, but also by the soils present, with conifers tending to dominate on the sandy soils. The soils to the north of the region, especially in Michigan, tend to be very sandy and, therefore, droughty. Although the vegetation models considered this influence, the scale of the variation in soil effects is much finer than can be represented in the models. Therefore, soil effects contribute to uncertainties in the projections.

Changing Natural Productivity

The current assessment results suggest two general trends in changing net primary productivity (NPP). NPP is simply the amount of living plant tissue gained by growth, less the amount lost through death, relocation, per unit area, per unit interval of time – it is also a key indicator of ecosystem degradation or improvement. First, the modification of landscapes through landuse has a much greater impact on the level of net primary productivity than will the projected levels of climate change. Estimates from biogeochemistry models under changed climate scenarios project changes in productivity between a decrease of 10% and an increase of about 50%. However, active management takes over half the land out of natural production and causes a current decrease in net primary productivity of about 50%. The changes in natural net primary productivity as a result of climate change are going to be restricted to those areas that are not actively managed.

The second trend is a likely increase in productivity to levels slightly above present levels. The best guess value, is an increase of about 20%. This increase comes about from longer growing seasons and increased water use efficiency. Growth chamber experiments with young aspen in Northern Michigan show between 15 and 30% increase in productivity due to elevated CO_2 levels alone, depending on site conditioms (Note: This estimate does not account for any changes in disturbance regimes, increase in nitrogen deposition, any change in cloudiness, or changes in landuse). However, rapid rates of landuse change could overwhelm changes due to climate change. Given the vegetation scenarios described above, the forests will need to change their mix of species before attaining this increased productivity. The amount of time it will take for this to occur is still debatable, although prior studies suggest a time frame on the order of 200 years [6-5]. So, if mortality substantially within the time frame of this assessment (an uncertain possibility), then decreases in productivity are more likely.

Evaluating Economic Impacts of Climate Change on the Forestry Industry

Despite the importance of landuse on net primary productivity, the impact that climate change (alone) would have on the forest industry in the Great Lakes region could be substantial. As indicated in the above section, important timber species (aspen, jack pine, red pine, white pine, etc.) will be lost from our region. The socioeconomic implications of the type of forest land transition shown in Figure 6.4 are significant. From a purely economic point of view, perhaps the greatest loss would be to the strong virgin pulping/wood fiber industry that now exists in the Great Lakes region. A strong shift toward oak-hickory would completely eliminate the soft wood pulp industry and create difficulty for board mills, OSB plants, and other forest product industries that rely primarily on softwood feedstocks. This would effectively require closing many mills in Michigan and Wisconsin unless significant technological advances were made that allow the greater consumption of hardwood fiber for use in these threatened industries.

The effect of this transition on consumer wood products, manufactured wood products, and other wood-related specialty industries is less clear. If these industries are flexible and capable of switching from softwoods to hardwoods as raw materials, then they will (continue to) do well. From a more social perspective, the effect will also be significant. Clear negative impacts to the quality of life and tourism dollars may occur with the disappearance of aspen and many of the characteristic conifers, such as jack, red and white pine that characterize today's landscape of the northern Great Lakes region. Logging has already reduced the abundance of red and white pine, but they remain as characteristic species in Itasca State Park, the Boundary Waters Canoe Area, and, in lesser abundance, in the Porcupine Mountains and other parks that attract visitors to the region.

Coping Strategies

There seem to be few options for halting this significant change in the regional forest ecosystem. Therefore the most effective approach for coping with this change is anticipating its effects and trying to mitigate them through steps that prepare citizens and industries for the changes.

The following ideas for coping strategies came out of the Upper Great Lakes Region Workshop. First, a reasonable response strategy within the forestry and land management communities in the Upper Midwest is to monitor the health of the forests in response to their changing environment from climate change, changing air quality, pest and disease outbreaks, and forest fragmentation due to development. Fire and pest management strategies may need to be reconsidered from a changing climate perspective (Figure 6.6). The incorporation of integrated pest management and prescribed burning may reduce the indirect effects of these disturbances with a changing climate.

Landuse conflicts may occur as a more dispersed settlement pattern continues to develop and as competition among vari-

Figure 6.6: Asian longhorn beetle infestation in Chicago: before, during, and after cleanup. The only control available now is to identify which trees are infested, cut them down, and chip them into tiny pieces. Such an approach can turn a tranquil neighborhood with tree-lined streets into a barren landscape. Source: Agricultural Research Library Photo Gallery; Photo by Michael T. Smith.

ous landuses change with changing climate. Policies, such as landuse planning and/or "sprawl" taxes, might be used to minimize landuse conflicts. However, it must be understood that current strategies are failing. For example, attempts to minimize sprawl (e.g., Subdivision Control Act, zoning) in the past have not met with great success. The political costs of abridging land ownership rights in the region could be high.

Where possible, some attempt should be made to facilitate the migrations of plant species with the shifting of ecological zones. The establishment of migration corridors was suggested at the Upper Great Lakes Region Workshop as a possible mechanism to reduce the effects of fragmentation. However, maintaining a corridor may not be successful if flowering is limited due to climatic changes. Following harvest, tree species that are better suited to a changed climate might be planted to encourage adaptation of the ecosystem. Species and genetic diversity should also be encouraged to improve natural adaptive capacity.

Finally, and most importantly, public and private education programs regarding the potential risks and consequences associated with rapid changes in climate should be in place. For example, the potential for increasing fire danger associated with warmer and drier conditions should be communicated to homeowners in high fire-risk ecosystems. The increased potential for flooding associated with increases in the frequency of heavy precipitation events should be communicated to flood plain landowners. The pulp and wood product industries should incorporate the change in forest patterns into capitalization plans as soon as possible (in these capital intensive industries decisions are frequently made with 20-30 year time horizons). Local communities should begin a program of planting tree species on their streets and parks that will thrive in the changed climate in order to avoid effects like those caused during the Dutch Elm disease epidemic in the 1960s and 1970s. While none of these steps is likely to replace lost revenues or other industrial activity, it is possible that the devastating effects that occur when change encounters an unprepared industry could be mostly prevented.

Information & Research Needs

Although the Upper Great Lakes Region Workshop identified several information needs, two are particularly relevant to the assessment presented here.

One important need is to use climate output from atmospheric models with higher resolution. The range-limit results for tree species were obtained in the present study using output from a coarse resolution GCM - that does not include the effects of the Great Lakes. Some of the finer-scale aspects of the results in Figures 6.4 might therefore differ if output from a higher-resolution regional climate model, that accounted for lake-effect cloudiness, precipitation, temperature moderation, and (severe) storm development, for example, were used. A better understanding of the relationships between bioclimatic variables and range limits should also lead to better predictions of the impacts of climate change on tree species.

Another important information need is the one to couple models of ecosystem productivity with models of landuse change to study change under altered climate. The magnitude of the landscape alterations in the region suggest that land management will continue to be important, perhaps more so, in determining the productivity of the landscape.

Dynamic (transient) models of ecosystems, like the gap models used by Solomon [6-6] need to be combined with spatially distributed models of landscape function in a manner similar to He et al. [6-15]. Spatially and temporally explicit models allow for the incorporation of a number of effects not already considered in these assessments. These include the response of disturbance regimes to climate change, the effect of seed dispersal on the rate of species establishment, and the analysis of patchy landscapes (i.e. landscapes that are not completely natural).