



# Climate Change Impacts and Adaptation in Forestry: Responses by Trees and Markets

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The forest sector—forestry and forest industries—plays an important role in the global climate change debate. The sector influences the global carbon cycle through the sequestration of atmospheric carbon in forests and is in turn influenced by global climate change through its impacts on the rates of forest growth and climate-induced changes in natural disturbances such as fire. Similar to agriculture, the effects of climate variability and change on forests and forest industries were examined in the US National Assessment (Joyce et al., 2001). Climate change may alter the productivity of forests, shifting resource management, economic processes of adaptation, and ultimately forest product harvests both nationally and regionally. In regions where climate change reduces timber growth, smaller timber volumes will be available for harvest in both existing forest stands and in those regenerated in the future. The reverse would be true in regions experiencing increased timber growth. In addition, differential impacts of climate change in forestry and agriculture could lead to land use shifts as one possible adaptation strategy. For example, if climate change results in relatively higher agricultural productivity per acre, some acres may be converted from forests to agricultural use.

Such changes would alter the supply of products to national and international markets, changing the prices of forest products and the economic well-being of both consumers and producers. Consumers, in turn, would shift their patterns of consumption between forest and nonforest products.

Producers would change both the types of management they practice (planting, thinning, and other cultural treatments) and the ages at which they harvest trees, depending on the type of owner (private or public). This paper reviews key results for the forest sector highlighted in the US National Assessment (Joyce et al., 2001). The analysis described in this paper was conducted with the same model as was used in the agricultural analysis described in the Reilly article in this issue of *Choices*. During the National Assessment, a joint forestry and agriculture climate impact scenario was conducted; in this paper, we focus on the forestry results from that scenario. The results for the agricultural sector are qualitatively similar to those reported in the Reilly article.

## Climate Change in the Woods

One difficult aspect associated with modeling climate change impacts on forests is that climate change effects will likely differ between existing trees and trees regenerated in the future (naturally or planted). Native forests are adapted to the local climate and the variability of that climate. Changes in the climate will affect these existing trees by changing growth rates, tree mortality, and seed production for the next generation of forests. For existing trees, other climate change impacts could include increased risk of forest fire and mortality associated with increased insects and diseases. Our understanding of the relationships between the existing trees and climate is the basis for modeling the future impact of climate. Trees planted in the

### **Impacts of Climate Change on the Forest Sector**

- **Land uses may change.** Compared to the baseline for the Assessment, less cropland is projected to be converted to forests under the climate change scenarios.
- **Forest composition and carbon sequestration could shift.** The type of forests found in some regions might change, altering the amount of carbon stored in forests and the type of wood products produced.
- **Patterns of natural disturbances such as fire, insects, and disease may change.** The National Assessment indicated the possibility of a 10% increase in the seasonal severity of fire hazard over much of the United States under both climate scenarios.
- **Producers and consumers could be impacted.** In the aggregate, where climate change was projected to induce yield increases, consumers were found to benefit but not producers. Projections of yield decreases had the opposite effect.
- **Adaptation in the sector could limit effects.** Options include land market adjustments, interregional migration of production (e.g., northerly migration of productive capacity), substitution in consumption between wood and nonwood products (reflected in overall growth in wood products use) and between sawtimber and pulpwood, and alteration of stand management.

future, however, will grow entirely in an environment with altered climate; their response to these climate changes could include surprises in terms of the volume growth, product yield, and product quality.

Impacts on forests arise from increases in atmospheric CO<sub>2</sub> concentration, changes in temperature regimes, and variations in annual rainfall patterns. Such shifts could alter basic physiological processes in trees and soils, influencing growth and the yield of commercial products over time. The actual time pattern of change will be complex, owing to lags between atmospheric changes, climate effects, and biological responses. Economic impacts resulting from growth changes will be further delayed due to the length of forestry rotations (generally two or more decades). Any examination of the effects of climate change on forests needs to consider forest rotation decisions as well as lags between the onset of climate change and the resulting biological impacts.

Given considerable uncertainty about the biological impact of global change on forests, the US National Assessment Forest Sector Team (Joyce et al., 2001) examined four alternative scenarios of the biological response of forests to climate change

(reflected by changes in forest growth rates). Climate projections were obtained from the same two global circulation models (GCMs produced by the Canadian Climate Center and the Hadley Center) used in the agricultural assessment. These climate scenarios were used to model potential ecological changes in forests in two ecological process models—Century and the Terrestrial Ecosystem Model (Vegetation-Ecosystem Modeling and Analysis Project, 1995)—that simulate the impacts of climate on forest productivity, considering the influence of environmental factors such as temperature, precipitation, and soil texture on the cycles of carbon, nutrients, and water in forest ecosystems. The two climate scenarios and two ecological models generate four estimates of changes in vegetation production in US forests by region.

As noted in the Reilly article, the two climate scenarios suggest a generally more productive forest environment in the future due to a warmer and wetter climate for the United States. As a result, the ecological process models project increases in total vegetation carbon storage over the century; timber growth in hardwoods and softwoods generally increases under all four cases. Some interesting regional differences are projected during the century. The largest change among forest types modeled is in the Northeast region, where forest growth in the oak-hickory type increases about 0.3% annually by 2100. In contrast, forest growth declines in the South in some decades. Compared to the Hadley scenario, the Canadian scenario is much warmer and generally drier, particularly in the Southern United States. Thus, under the Canadian scenario, some currently forested area is projected to experience a drought-induced loss of carbon. Forest growth is consequently projected to decline in the Southern US between 2010 and 2040 under the Canadian scenario, although by 2100, forest growth in this region is projected to rebound and increase relative to the baseline.

Estimates of changes in forest production for each climate change and ecological scenario were incorporated into an economic model of land use and management. The overall results suggest that consumers gain and producers lose, although the changes are not large. Net market welfare increases from 0.05% to 0.18% over this century. Pulpwood prices are estimated to rise approximately 3.1–3.8% during the period 2020–2050, while sawtimber

prices are projected to decline 3.7–6.4%. Pulpwood price increases result from reduced growth over large areas of young forests projected during the near term, particularly in the Canadian scenario.

### **Forest Producers, Consumers, and Choices**

Understanding the role of adaptation in forestry is important for assessing the overall impact on markets. One general conclusion from the US National Assessment, which is consistent with earlier studies, is that timber and wood product markets and forest landowners will adjust and adapt to climate change in ways that act to limit economic effects. Among choices for the millions of private landowners affecting adaptation are options to shift land uses. These shifts are occasioned by differences between the forest and agriculture sectors in lead times required to shift production from one crop or cropping method to another. Agricultural rotations are typically one to several years, compared to one to several decades in forestry. This affects the likely mix of afforestation, reforestation, and deforestation under different global climate change scenarios for forest industry and nonindustrial private owners—groups that tend to have notably different land management objectives.

Several findings related to adaptation from the US National Assessment on forestry impacts include:

**Land Use Choice.** Compared to the baseline for the assessment, less cropland is projected to be converted to forests under the climate change and ecological scenarios investigated in the US National Assessment. Although climate change is likely to affect the margin between agriculture and forestry in specific locations, aggregate productivity changes in forestry appear to outstrip aggregate productivity changes in agriculture.

**Forest Composition and Sequestration.** Economic models suggest that the overall area of forests in the United States is projected to expand less than the baseline under climate-change scenarios. Biogeographical models (although they do not account for price effects) suggest that the composition of forests is also likely to change. In particular, potential habitats for trees favored by cool environments are very likely to shift north. Eastern land area associated with aspen, sugar maple, and birch, for example, is

likely to decline, whereas oak/hickory and oak/pine forests could possibly expand. As a result, the type of forests that individuals see on the landscape may change, altering the amount of carbon stored in forests and the type of wood products produced across these landscapes.

**Changes in Natural Disturbances such as Fire, Insects, and Disease.** Natural disturbances such as fire, insects, and disease have a large impact on forests across the United States, and climate has a large impact on the occurrence, frequency, and intensity of these natural disturbances. It is difficult to estimate the precise impact of climate change on these disturbances. However, analyses in the National Assessment indicated the possibility of a 10% increase in the seasonal severity of fire hazard over much of the United States under both of the climate scenarios. Warmer temperatures in the western United States have already enhanced the opportunities for insect spread across the landscape (Crozier, 2002). It is very likely that these natural disturbances will be altered by climate and will have an impact on US forests and forestry.

**Producer and Consumer Impacts.** In the aggregate, where climate change was projected to induce yield increases, consumers were found to benefit but not producers. Projections of yield decreases had the opposite effect. Producers' income from forestry activities, therefore, appears to be most at risk from climate change.

**Adaptation Alternatives.** The forest sector was found to have adaptation or adjustment mechanisms that may help to mitigate climate change impacts, including land-market adjustments, interregional migration of production (e.g., northerly migration of productive capacity), substitution in consumption between wood and nonwood products (reflected in overall growth in wood product use) and between sawtimber and pulpwood, and alteration of stand management. Stand-management options include types of site preparation and planting stock, fertilization, thinning, salvage of dead or dying trees, rotation age, and harvesting patterns among owners and regions.

## Complications in a Complex World

For decision makers, the long time periods between germination of a tree seed and maturation of a forest crop mean that adaptation may take place at multiple times during a forestry rotation. The adjustment dynamics will be complex, in part, because better information on climate change and its effects will emerge over the course of a rotation. In forestry, longer rotation lengths complicate the development of data on actual biological responses of trees and forests to global change. Those rare long-term studies of tree growth have provided insights into relationships between trees and climate (particularly drought impacts). However, the uncertain effect of increased carbon dioxide on trees is only now being studied in comprehensive long-term experiments on how trees behave when exposed to alternative CO<sub>2</sub> levels and other stresses (such as ozone). Little is known about how these experimental results on individual trees generalize to stand, forest, and regional levels or to other tree species.

In addition to lengthy rotations for forest crops, the impacts resulting from climate change are unclear because of uncertain future changes in population, land use, trade in wood products, consumption of wood products, recreation patterns, and human values. For example, if human needs from forests increase over the next 100 years and imports are limited, the socioeconomic impacts from climate change would be greater than if needs were low or products could be imported from areas where climate might increase forest growth. These uncertainties increase the value of using scenario analysis in planning policy interventions in the forest sector. Projecting impacts of global climate change on the US forest sector helps to place in context concerns about economic shifts and the importance of human actions in adaptation and mitigation.

Based on the magnitude of changes in forest yields due to climate change as estimated by ecological models, we are led to expect relatively small aggregate welfare and economic impacts at a national level (Joyce et al., 1995, McCarl et al., 2000, Shugart, Sedjo, & Sohngen, 2003). At present, however, these yield-impact estimates have a wide range of uncertainty. Short-term impacts could become large, if climate change were to

involve significant shifts in regional weather patterns or dieback in existing stands with large losses in timber stocks.

This paper has not addressed the impact of climate change on nonwood forest products and services, such as biodiversity, recreation, edible fruits, and other nonwood products. In general, the influences of climate change on these goods and services are more difficult to assess, because our understanding of the demand for these products is incomplete globally and because of high uncertainty regarding ecological effects of climate change. It is likely, however, that the impacts on nonwood forest products will vary from place to place, depending on the nature of climate change. Impacts on forest recreation, for example, will probably vary by the type and location of activity. Some activities, such as beach recreation at mountain lakes, might benefit as a result of extended seasons. Other uses that are sensitive to average temperatures and climatic variability, such as cold-water fishing in streams and snow skiing, may lose. Industrial wood products, in contrast, may be less susceptible to climate change due to global market systems that allow wood trade from region to region. There are fewer such established links for nonwood forest products, however, so that they are likely to exhibit more vulnerability to climate change. Impacts on some nonwood products, however, would be global regardless of whether or not they are traded across regions. For example, biodiversity is a global public good, with potentially high public value in all regions.

## For More Information

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