

US National Climate Change Assessment on Forest Ecosystems: An Introduction

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Atmospheric concentrations of carbon dioxide (CO₂) and other greenhouse gases have been increasing since the beginning of the industrial revolution in 1850. Over the next century, increasing gas concentrations could cause the temperature on the surface of the Earth to rise as much as 2–3°C over historic mean annual levels. Variation in annual climate could also increase.

The United States experienced one indication of climate change in 1988: The summer of that year was one of the hottest, driest ever recorded across the nation. Barges were stranded on the Mississippi River, and forest fires burned millions of acres in the western United States. In the eastern United States, temperatures were so high that many factory assembly lines had to be shut down. The former Soviet Union states and China also experienced severe drought, while Africa, India, and Bangladesh witnessed torrential rains and flooding.

These events triggered televised congressional debates, which concluded that atmospheric greenhouse gas inputs would very likely increase the intensity and severity of weather patterns during the next 100 years. The potential negative effects of global warming—melting of polar ice caps, a rise in the sea level, reduced agricultural and forest productivity, water shortages, and extinction of sensitive species—were also discussed.

These findings prompted the passage of the 1990 Global Change Research Act (GCRA) and the establishment of the US Global Change Research Program (USGCRP). The program sponsors ongoing research (over \$1.6 billion in 2000) at several federal agencies, including the National Aeronautics and Space Administration, Department of Energy, US Department of Agriculture, Environmental Protection Agency, National Institutes of Health, Department of Commerce, and National Science Foundation, among others (USGCRP 1999). In addition to providing a mechanism for funding research on global change, the GCRA mandates that an assessment be conducted periodically to summarize research findings. Begun in 1997, the first *National Assessment of the Potential Consequences of Climate Variability and Change* was published in 2001 (USGCRP 2001). The assessment was a

collaboration between federal and nonfederal researchers, resource managers, and users. The assessment is divided into five sectors: (1) water resources and availability, (2) agriculture and food production, (3) human health, (4) coastal areas, and (5) forests. These sectors represent important or potentially sensitive US resources that could be adversely affected by climate change. The assessment also includes over 20 regional studies, which examine the impacts of climate change for specific geographical areas of the United States. This special section of *BioScience* focuses on a summary of research findings from the forest sector and regional findings of the 2001 national assessment (USGCRP 2001).

The impacts of climate change on the forest sector are divided into four categories: (1) forest processes, (2) biodiversity change, (3) disturbance interactions, and (4) socioeconomic change. These categories represent key interactions between a changing climate, forest structure or function, and human interactions with forests.

Forest processes

Forests provide water, timber, and pulp for residential and industrial use and are an important sink of atmospheric carbon dioxide (CO₂). Long-term changes in the mean and variance of air temperature, precipitation, atmospheric CO₂, and ozone (O₃) could have a significant impact on forest processes in the next century. Examination of national and regional scale forest-process models, combined with two transient and five static climate change scenarios, suggested that forests will experience slight to moderate (5%–30%) increases in forest productivity (Aber et al. 2001). Although most of the climate scenarios suggest a generally more productive environment, some regions may experience significant reductions (greater than 20%) in forest productivity, especially if

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other stresses (e.g., changes in fire frequency and ozone) are included in the analysis.

In the southern United States, the Hadley scenario predicted much wetter future conditions compared with the Canadian scenario. The MC1 model predicted that fire frequency and severity would increase with the drier Canadian scenario. The combination of increased fire and drier conditions caused the MC1 model to predict that under the Canadian scenario, carbon accumulation would decrease across the southern United States. Conversely, under the wetter Hadley scenario, carbon accumulation would increase across the region (Aber et al. 2001).

Forest water-use efficiency may increase because of higher atmospheric CO₂ concentrations, but in some parts of the United States leaf area and associated evapotranspiration from forests may increase, resulting in decreased water flow from forests. Reductions in water flow could be most pronounced in the plains states, where severe reductions in stream volume could impair the use of the Mississippi River intercoastal waterway. Largely because of increased precipitation, the western United States may experience a 10%–60% increase in water flow.

Biodiversity change

Climate and land use are the two major factors controlling biological diversity. Species richness generally increases with increasing air temperature and precipitation. As the climate changes during the next century, biological diversity also will change, favoring some species and geographic areas over others. Under all of the climate scenarios, many of the northern US forest groups that are adapted to cooler temperatures will migrate northward, while isolated communities of other species, such as red spruce, may become extinct within their current region. As the range of northern species moves further north, southern mixed pine and hardwood ecosystems will expand northward in their range, greatly increasing the geographic distribution of southern forest communities (Hansen et al. 2001). Birds and mammals may experience reduced species richness across the southern United States and increased species richness across the warming northern section of the country (Hansen et al. 2001). However, ecosystems are complex communities and current models only associate biodiversity with existing environmental conditions. If climate change occurs faster than new ecosystem structure and function can be developed, then the historical relationships between plant, animal, and climatic conditions may not be reestablished and biological diversity will be reduced.

Disturbance interactions

Fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, and ice storms are the most important natural disturbance mechanisms for forest change in the United States. The impacts of these disturbances are highly variable over time and space. Some disturbances, such as hurricanes and ice storms, may be infrequent (i.e., one major event every 3 to 10 years) but have extreme (i.e., near-

complete destruction), periodic impacts on large forests areas (more than 10⁴ km²). Other disturbances such as windstorms may be more frequent (i.e., hundreds per year) but individually affect a smaller area (less than 10² km²).

Although much has been learned about the impacts of individual disturbances on forest structure and function, little research on the interactions of climate and disturbance has been done (Dale et al. 2001). From our current understanding, some disturbances will probably increase in severity (e.g., insect and pathogen outbreaks), shift in geographic region (e.g., ice storms), or shift in frequency (e.g., fire). Data are insufficient to indicate whether the frequency or severity of some disturbances such as hurricanes and drought will increase or decrease (Dale et al. 2001). However, climate change will probably shift forest ecosystem distribution across much of the nation (Hansen et al. 2001). During the climate transition, forests may be more predisposed to other disturbance factors, such as insect and disease outbreaks. The amount of forest area burned may increase by 25%–50% as increased forest productivity initially builds fuel loads and subsequent droughts fuel fire occurrence (Aber et al. 2001).

Socioeconomic change

Long-term forest productivity is important to many states' sustained economic development and to national growth (Aber et al. 2001). Climate change is generally expected to boost forest productivity more than 20% at the national scale (Aber et al. 2001). Assuming there are no major shifts in timber demand, forest timber volume will increase, as will market welfare, and timber prices will decrease during the next century (Irland et al. 2001).

In regions such as the southern United States, where forest products are either the first or second most important crop, there may be serious losses in revenue and jobs. Climate change may also have an impact on the recreation industry. The southern United States may lose important economic revenues as coldwater fisheries move northward and marginally successful southern winter recreation industries are driven out of business by higher operating costs and shorter seasons (Irland et al. 2001).

The northern United States may be negatively affected through a reduction in tourism associated with fall foliage change, as more colorful species such as sugar maples are replaced with dull-colored oaks and hickories. However, the western United States may benefit from the additional precipitation, which could increase the availability of water-based recreation.

Coping strategies and future research

In addition to examining climate change impacts on these four forest categories, we address potential coping strategies that could be used to reduce the impacts of climate change. From our analysis, we concluded that future research should focus on interactions between climate and other stresses, and on how changes in forest structure and function interact with

socioeconomic change. Only through better understanding can future forest managers cope with our changing environment.

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This bibliography of peer-reviewed and gray literature (including journal articles, newspaper articles, reports, Internet-accessible material) focuses on environmental change—global warming or ozone depletion—and its impacts on plant and animal species and critical supporting ecosystems. The bibliography already comprises 2880 citations, and it will be updated every two months. Ultimately, each entry will be categorized in a variety of ways, permitting searches by key word and compilations by subject, region, or author. Any corrections or suggestions for additional citations should be sent to Wil Burns (e-mail: wburns@pacinst.org) at the Pacific Institute (Web site <http://pacinst.org/wildlife.html>).

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