Executive Summary

The forest sector technical report is a sector-wide scientific assessment of the current condition and likely future condition of forest resources in the United States relative to climatic variability and change. The assessment provides technical input to the National Climate Assessment (NCA) and serves as a framework for managing forest resources in the United States. The report provides technical input to the 2013 NCA developed by the U.S. Global Change Research Program (USGCRP).

The Global Change Research Act of 1990 requires the USGCRP to produce the NCA for the President and the Congress every four years, analyzing the effects of global change on multiple sectors and regions in the United States. The USGCRP is responsible for preparing the report based on technical information provided by public agencies and nongovernmental organizations. The NCA evaluates the effects of global change on agriculture, forests, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity, projecting major trends forward for up to 100 years.

In addition, the USGCRP is tasked with providing a coordinated strategy and implementation plan for assessing the effects of a changing climate on the Nation. This strategy is being developed to provide support to the NCA and establish a mechanism for an ongoing assessment capability beyond the 2013 report.

The forest sector technical report is the key technical input to the NCA forest sector chapter. To provide national stakeholder input to the forest sector technical report, a workshop was held in Atlanta, Georgia, on July 12–14, 2011, to solicit input from public, private, and tribal forest stakeholders, nongovernmental organizations, academics, professional organizations, private corporations, and federal agencies. These stakeholder suggestions helped to frame the subject matter content and management options in the report, ensuring relevance for decisionmakers and resource managers.

The forest sector technical report builds on the portion of the 2009 NCA that discussed forest ecosystems and incorporates new findings from scientific and management perspectives. The introduction provides an overview and discusses interrelated aspects of biophysical and socioeconomic phenomena in forested ecosystems that may be affected by climatic variability and change, followed by these chapters:

- Effects of Climatic Variability and Change
- Climate Change, Human Communities, and Forests in Rural, Urban, and Wildland-Urban Interface Environments
- Adaptation and Mitigation
- Improving Scientific Knowledge
- Future Assessment Activities
- Conclusions

It is difficult to conclude whether recently observed trends or changes in ecological phenomena are the result of human-caused climate change, climatic variability, or other factors. Regardless of the cause, forest ecosystems in the United States at the end of the 21st century will differ from those of today as a result of changing climate. Below we discuss the most important issues that have emerged from the report, including a brief summary of regional issues.

Effects of Climate Change on Ecosystem Structure, Function, and Services

A gradual increase in temperature will alter the growing environment of many tree species throughout the United States, reducing the growth of some species (especially in dry forests) and increasing the growth of others (especially in high-elevation forests). Mortality may increase in older forests stressed by low soil moisture, and regeneration may decrease for species affected by low soil moisture and competition with other species during the seedling stage. Most models preject that species habitat will move upward in elevation and northward in latitude and will be reduced in current habitats at lower elevations and lower latitudes. New climatic conditions may “move” faster in some locations than tree species can disperse, creating uncertainty about the future vegetation composition of these new habitats.

The high genetic diversity of most tree species confers tolerance of a broad range of environmental conditions, including temperature variation. Therefore, in many species, tree growth and regeneration may be affected more by extreme weather events and climatic conditions than by gradual changes in temperature or precipitation. Longer dry seasons and multiyear droughts will often become triggers for multiple stressors and disturbances (e.g., fire, insects, invasive species, and combinations thereof). These pulses of biophysical disturbance will change the structure and function of ecosystems across millions of hectares over a short period of time, focusing pressure on the regeneration stage of forest ecosystems. Increased atmospheric carbon dioxide (CO_2) and nitrogen deposition will potentially alter physiological function and productivity of forest ecosystems, with considerable variation in response among species and regions.

The effects of climate change on water resources will differ by forest ecosystem and local climatic conditions, as mediated by local management actions. Higher temperature during the past few decades has already decreased snow cover depth, duration, and extent, a trend that will probably continue with further warming. Decreased snow cover will exacerbate soil moisture deficit in some forests, which may decrease tree vigor and increase susceptibility of forests to insects and pathogens. As climatic extremes increase and forest ecosystems change, water produced from forest lands may become more variable and of lower quality.

Forest growth and afforestation in the United States currently account for a net gain in carbon (C) storage, offsetting approximately 13 percent of the Nation's fossil fuel CO_2 production. During the next few decades, Eastern forest ecosystems are expected to continue to sequester C through favorable response to elevated CO_2 and higher temperature, although retention of C will depend on maintaining or increasing total forest area. Western forest ecosystems may begin to emit C if wildfire area and insect disturbance increase as expected.

Future changes in forest ecosystems will occur on both public and private lands and will challenge our ability to provide ecosystem services desired by society, especially as human populations continue to grow and demands for ecosystem services increase. Climate change effects in forests are likely to cause losses of ecosystem services in some areas (e.g., timber production, water supply, recreational skiing), but they may improve and expand ecosystem services in others (e.g., increased growth of high-elevation trees, longer duration of trail access in high-snow regions). Some areas may be particularly vulnerable because current infrastructure and resource production are based on past climate and the assumption of steady-state natural resource conditions. Any change in forest ecosystems that affects water resources will typically result in a significant loss of ecosystem services.

Effects of Disturbance Regimes

The most rapidly visible and significant short-term effects on forest ecosystems will be caused by altered disturbance regimes, often occurring with increased frequency and severity. Interacting disturbances will have the biggest effects on ecosystem responses, simultaneously altering species composition, structure, and function. The type and magnitude of disturbances will differ regionally and will pose significant challenges for resource managers to mitigate and reduce damage to resource values:

- Wildfire will increase throughout the United States, causing at least a doubling of area burned by the mid-21st century.
- Insect infestations, such as the current advance of bark beetles in forests throughout the Western United States and Canada, will expand, often affecting more land area per year than wildfire.
- Invasive species will likely become more widespread, especially in areas subject to increased disturbance and in dry forest ecosystems.
- Increased flooding, erosion, and movement of sediment into streams will be caused by (1) higher precipitation intensity in some regions (e.g., Southern United States), (2) higher rain:snow ratios in mountainous regions (western mountains), and (3) higher area burned (western dry forests). These increases will be highly variable in space and time, affecting decisions about management of roads and other infrastructure, as well as access for users of forest land.
- Increased drought will exacerbate stress complexes that include insects, fire, and invasive species, leading to higher tree mortality, slow regeneration in some species, and altered species assemblages.

Managing Risk and Adapting to Climate Change

A risk-management framework for natural resources identifies risks and quantifies the magnitude and likelihood of environmental and other effects. Although risk management frameworks have been used (often informally) in natural resource management for many years, it is a new approach for projecting climate change effects, and some time may be needed for scientists and resource managers to feel comfortable with this approach. Risk assessment for climate change must be specific to a particular region and time period, and it needs to be modified by an estimate of the confidence in the projections being made.

Ecosystem services derived from forests are produced in (1) rural areas, where human population densities are low and forest cover dominates; (2) urban settings, where trees may exist in low densities but provide high value for direct ecosystem services; and (3) transition zones between rural and urban settings (wildland-urban interface [WUI]). Climate change will alter ecosystem services, perceptions of value, and decisions regarding land uses. Outcomes for people will be determined by the interaction between changes in biophysical environments (e.g., climate, disturbance, and invasive species) and human responses to those changes (management and policy). In recent years, C sequestration policy options and increased use of bioenergy emphasize both climate change-human interactions on forests and the role of forests in mitigating climate change.

Land use shifts in rural areas under climate change could involve conversion of forests to agricultural uses, depending on market conditions. Climate change is expected to alter productivity (local scale) and prices (market scale). The extent of WUI areas and urban areas are projected to increase, often at the expense of rural forests. Higher temperature coupled with population growth will increase the extent and value of urban trees for mitigating climate change effects, but these two factors may also increase the difficulty of keeping trees healthy in urban environments.

The ability of communities with resource-based economies to adapt to climate change is linked to their direct exposure to these changes, as well as to the social and institutional structures present in each environment. Human communities that have diverse economies and are resilient to change today will also be better prepared for future climatic stresses, especially if they implement adaptation strategies soon. Federal agencies have made significant progress in developing scientifically based principles and tools for adapting to climate change. These tools and techniques are readily available in recent materials that can be supplied to public, private, and tribal land owners and managers for their use in forest management.

Regional Effects of Climatic Variability and Change

The report incorporates a regional perspective and highlights key issues for the forest sector in the NCA regions.

Alaska

- Alaskan forests are regionally and globally significant, and changes in disturbance regimes will directly affect the global climate system through greenhouse gas emissions and altered surface energy budgets.
- Climate-related changes in Alaskan forests have societal consequences, because some forests are in proximity to (urban and rural) communities and provide a diversity of ecosystem services.
- In interior Alaska, the most important effects of climate change are permafrost thawing and changes in fire regimes.
- South-central Alaska will be sensitive to climate change because of its confluence of human population growth and changing disturbance regimes (insects, wildfire, invasive species).
- In southeast Alaska, climatic warming will affect forest ecosystems primarily through effects on precipitation (i.e., snow versus rain).

Hawaii and the Pacific Territories

- Pacific islands are vulnerable to climate change because of (1) the diversity of climate-related stressors; (2) low financial, technological, and human resource capacities to adapt to or mitigate projected effects; and (3) diverse and often more pressing concerns affecting island communities.

- Island societies and cultures based on traditional knowledge and institutions have provided resilience to these communities during past stressful periods. Contributing to resilience are locally based ownerships and management, subsistence economies, tight linkages between landowners and government, and opportunities for migration.
- The direct effects of changing climate on forests will be significant and strongly dependent on interactions with disturbances, especially novel fire regimes that are expanding into new areas because of flammable invasive species.
- For low-lying islands, enhanced storm activity and severity and sea level rise will cause the relocation of entire communities, with the first climate refugees already having to relocate from homelands in the region. For high islands, higher temperature, expanded cover of invasive species, and higher fire frequency and severity will affect ground-water recharge, downstream agriculture, urban development, and tourism.

Northwest

- Based on projections of distribution of tree species and forest biomes, widespread changes in the distribution and abundance of dominant forest species are expected, although the results of modeling studies differ. Forest cover will change faster via disturbance and subsequent regeneration responses, rather than through slow adjustment to gradual warming.
- Climate is projected to become unfavorable for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) over 32 percent of its current range in Washington, and up to 85 percent of the range of some pine species may be outside the current climatically suitable range.
- Area burned and biomass consumed by wildfire will greatly increase, leading to changes in ecosystem structure and function, resource values in the WUI, and expenditures for fire suppression and fuels management.
- A combination of higher temperature and dense, low-vigor stands have increased vulnerability to bark beetles and other insects, and mortality is currently high in some dry forests.

Southwest

- Disturbance processes facilitated by climatic extremes, primarily multiyear droughts, will dominate the effects of climatic variability and change on both short- and long-term forest dynamics.
- Although diebacks in species other than pinyon pine (*Pinus edulis* Engelm.) are not widespread, large fires and insect outbreaks appear to be increasing in frequency and spatial extent throughout the Southwest.
- Increased disturbance from fire and insects, combined with lower forest productivity at most lower elevation locations, will result in lower C storage in most forest ecosystems. The fire-insect stress complex may keep many low-elevation forests in younger age classes in perpetuity.
- Increased fire followed by high precipitation (in winter in California, in early summer in much of the rest of the Southwest) may result in increased erosion and downstream sediment delivery.

Great Plains

- Trees occur along streams, on planted woodlots, as isolated forests such as the Black Hills of South Dakota, and near the biogeographic contact with the Rocky Mountains and Eastern deciduous forests, providing significant value in riparian areas, at higher elevations, and within agroforestry systems.
- Tree species in mountainous regions are expected to gradually become redistributed to higher elevations, with disturbances mediating rapid change in some locations.
- Climate-driven changes in hydrology are expected to reduce the abundance of dominant, native, early-successional tree species and increase herbaceous, drought-tolerant, late-successional woody species (including nonnative species), leading to reduced habitat quality for riparian fauna.

- The potential for increased wildfire hazard, longer droughts, insect outbreaks, and fungal pathogens, individually and in combination, could significantly reduce forest cover and vigor. Reduced tree distribution will likely have a negative effect on agricultural systems, given the important role of shelterbelts and windbreaks in reducing soil erosion.

Midwest

- Northern and boreal tree species at the southern edge of their current range will decrease in abundance and extent as their current habitat becomes less suitable (and moves northward) and reestablishment in a warmer climate becomes more difficult. Some forested wetlands may also disappear as the climate warms. Some oak and hickory species tolerant of low soil moisture may become more abundant.
- Increased drought and fire occurrence are expected to have rapid and extensive effects on the structure and function of forest ecosystems. Oak decline and invasive species are expected to become more common, contributing to stress complexes that include nearly two centuries of land use activities.
- Increased disturbance will tend to fragment forest landscapes that are already highly fragmented in terms of species, structure, and ownerships. This will reduce habitat connectivity and corridors for species movement.
- The large amount of private land and fine-scale fragmentation of forest landscapes will make it challenging to implement climate change adaptation. Outreach to private land owners will be necessary to ensure that climate preparedness is effective.

Northeast

- Stress complexes are especially important in northeastern forests, where climate interacts with nitrogen (N) deposition, tropospheric ozone, land use, habitat fragmentation, invasive species, insects, pathogens, and fire.
- A warmer climate will cause a major reduction of spruce-fir forest, moderate reduction of maple-birch-beech forest, and expansion of oak-dominated forest. Projections of change in suitable habitat indicate that, of the 84 most common species, 23 to 33 will lose suitable habitat under low- and high-emission scenarios, 48 to 50 will gain habitat, and 1 to 10 will experience no change.
- Warmer temperature will increase rates of microbial decomposition, N mineralization, nitrification, and denitrification, resulting in higher short-term availability of calcium, magnesium, and N for forest growth, as well as elevated losses of these nutrients to surface waters.
- Migratory bird species that require forest habitat are arriving earlier and breeding later in response to recent warming, with consequences for the annual production of young and their survival. Many bird species have already expanded their ranges northward.

Southeast

- Red spruce (*Picea rubens* Sarg.) and eastern hemlock (*Tsuga canadensis* [L.] Carrière), already declining in some areas, are projected to be extirpated from the southeast by 2100 as a result of the combined stresses of warming, air pollution, and insects.
- The majority of the Nation's pulp and timber supply is produced in the southeast, but if temperature continues to increase and precipitation becomes more variable, conditions for pine growth may begin to deteriorate. Even if regional forest productivity remains high, the center of forest productivity could shift northward into North Carolina and Virginia, causing significant economic and social impacts.
- Increasing demand for water from a rapidly growing urban population, combined with increased drought frequency could result in water shortages in some areas of the Southeast.
- Warmer temperature may increase decomposition of soil organic matter and emissions of CO_2, reducing the potential for C sequestration.
- Increased fire hazard and insect outbreaks will provide significant challenges for sustainable management of forests for timber and other uses, but may also motivate restoration of fire-tolerant longleaf pine (*Pinus palustris* Mill.) forests.

An Imperative for Action

Climate change will generally reduce ecosystem services because most human enterprises are based on past climatic environments and the assumption of static natural resource conditions. Increased forest disturbance will, at least temporarily, reduce productivity, timber value, and C storage, and, in some cases, will increase surface runoff and erosion. Changes in forest ecosystems that affect hydrology and water supply will typically result in a significant loss of resource value. Scientific principles and tools for adapting to these climate change effects focus on education, vulnerability assessment of natural resources, and development of adaptation strategies and tactics. The hallmark of successful adaptation efforts in the United States has been science-management partnerships that work collaboratively within public agencies and externally with various stakeholders. Several recent case studies of adaptation for national forests and national parks are now available and can be emulated by other land management organizations.

Although uncertainty exists about the magnitude and timing of climate change effects on forest ecosystems, sufficient scientific information is available to begin taking action now. Managing simultaneously for C and for on-the-ground implementation of adaptation plans is challenging in both public and private sectors; however, implementation can be increased through effective exchange of information and success stories. Land managers are already using "climate-smart" practices, such as thinning and fuel treatments that reduce fire hazard, reduce intertree competition, and increase resilience in a warmer climate. Building on practices compatible with adapting to climate change provides a good starting point for land managers who may want to begin the adaptation process. Establishing a framework for managing forest ecosystems in the context of climate change as soon as possible will ensure that a broad range of options is available for managing forest resources sustainably.

We are optimistic that a proactive forest sector will make the necessary investments to work across institutional and ownership boundaries by developing, sharing, and implementing effective adaptation approaches. This will be accomplished by (1) embracing education on climate science for resource professionals and the general public; (2) ensuring accountability and infusing climate change into organizational efforts (e.g., management plans and projects); (3) implementing an all-lands approach through collaboration across administrative, political, and ownership boundaries; and (4) streamlining planning processes and establishing projects on the ground. The twofold challenge of adapting to climate change and managing C in the broader context of sustainable forest management will require creativity by future generations of forest resource managers. In the short term, management strategies that are relatively inexpensive, have few institutional barriers, and produce timely results can be rapidly implemented. For adaptation, examples include reducing nonclimatic stressors in forests (e.g., nonnative pathogens), implementing fuel reduction, and reducing stand densities. For C management, examples include reducing deforestation, increasing afforestation, reducing wildfire severity, increasing tree growth, and increasing use of wood-based bioenergy. Specific strategies and actions will differ by location, inherent forest productivity, and local management objectives.

Coordinating adaptation and C management will help optimize implementation across specific landscapes. For example, fuel reduction treatments can reduce wildfire severity in dry forests (adaptation) and provide material for local bioenergy use (C management). In the near term, we anticipate that federal agencies will continue to lead the development of science-management partnerships and collaborative approaches to climate-smart management, although (static) legal, regulatory, and institutional constraints will continue to deter timely responses to (dynamic) climate-caused changes in forest ecosystems. Successful adaptation strategies and C management will likely accelerate across large landscapes as community-based partnerships integrate climate change-related concerns into sustainable stewardship of natural resources.