Introduction

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Throughout Earth's history, its climates have been changing, and biotic systems have mutated, migrated, and otherwise adapted as tectonic shifts have reconfigured the continents and polar ice caps have ebbed and flowed across the latitudes through glacial cycles. In our own era, there is growing evidence that changes in climate that in the past have taken place over the course of millennia are now taking place in a matter of decades. These accelerated changed in climate are challenge the ability of both human civilization and the natural systems on which it depends, to adapt quickly enough to keep pace. Through efforts like the Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change, leading scientists around the world have focused their energies on understanding the nature and implications of these changes, and the world's governments are striving to develop the institutions and resources to enable timely and effective actions to mitigate and adapt to changes that are anticipated or already under way.

The people and organizations charged with the conservation and sustainable management of the world's forests and their associated renewable natural resources are at the forefront of efforts to understand and address these challenges. As stated in recent report by a group of federal natural resource management agencies and nonprofit organizations, "Rapid climate change is the defining conservation issue of our generation… Indeed, preparing for and coping with the effects of climate change—an endeavor referred to as climate change adaptation—is emerging as the overarching framework for conservation and natural resource management" (Glick and others 2011).

Conserving biological diversity in the world's forests is a particular challenge as both plant and animal species are prompted to follow the climate-driven movement of the ecosystems and habitats in which they evolved (Hannah 2012; Hannah 2002; Lovejoy and Hannah 2005). Ecological communities disassemble as species capable of migrating do so, and those that are not remain behind. Those than can migrate now must traverse landscapes that in earlier epochs were not filled with highways, cities, farms, and other manifestations of a rapidly expanding human population that is relatively new on the geologic time scale. Designated parks, refuges, reserves, and other traditional approaches to protecting habitat are still important (Caro and others 2011), but may be less effective when the species themselves are on the move (Kareiva and others 2011). This is prompting biologists, resource management professionals, and policymakers to consider new approaches to conservation planning (Anderson and Ferree 2010), and strategies focused on large landscapes—vast areas that stretch from Yellowstone National Park to the Yukon, or from the southern Appalachians to Labrador (Anderson and others 2011). These immense landscapes encompass cities, towns, and agricultural working lands, as well as a mosaic of public and private forests that are all managed for different purposes and objectives. For these landscape-scale conservation strategies to be environmentally, economically and socially sustainable—and politically possible—new governance models must be developed to facilitate an unprecedented level of communication, coordination, cooperation, and collaboration (McLachland and others 2007; Marris 2011; Kareiva and others 2012).

Much more than wildlife habitat conservation is at stake. For thousands of communities across the nation, forests are key to maintaining adequate supplies of clean water to meet municipal, agricultural, and industrial needs. Forests in the headwaters and riparian areas of the nation's rivers and streams are low-cost, high-return guarantors of water quality, water supply, and favorable timing of seasonal flows. All of these are critical considerations in the western US and parts of the South where higher temperatures, prolonged droughts, and shifts in precipitation patterns are already causing economic and social disruptions (Milly 2008). Other regions in the eastern United States anticipate a continuing increase in precipitation in the form of extreme storm events, accentuating the essential role that intact forests serve in storm water control and flood mitigation.

The low-cost and largely self-maintaining "green infrastructure" that forests provide is vulnerable to both direct and indirect effects of climate change. The direct effects of drought, elevated temperatures, and changing precipitation patterns can be seen in reduced tree growth, lower survival rates in tree seedlings and young growth, and reforestation failures in the wake of natural disturbances. The loss of certain more climate-sensitive tree species within a forest can change the overall species composition or mix, eliminating food sources and habitat for native wildlife species.

Forests that are already under a high degree of environmental stress from these direct effects of climate change are more vulnerable to its indirect effects. Forests in many parts of the world are experiencing extraordinary and often unprecedented levels of mortality from insects and disease. Incidents involving even endemic or native pests and pathogens, which would normally kill only a small fraction of the trees in a forest, are in some regions causing near 100-percent mortality over areas of thousands of square miles (Allen and others 2002). The resulting large volume of dead and dying trees invites wildfires that themselves are unprecedented in size and severity (Brown and others 2004). Following events such as these, the harsher climate makes reforestation and ecological restoration that much more difficult and prone to failure, often leading to increased soil erosion, stream sedimentation, impacts on terrestrial and aquatic habitat, and damages to water supplies, storm water control, and flood mitigation.

These climate change effects are largely outside the experience and expertise of today's forest managers, on both public and private lands. The magnitude of these changes and the speed with which they are taking place are essentially unprecedented in the lifetimes of resource management professionals currently in the field. Even the knowledge base for forest management practices that has been built up over the past two centuries is itself based on forest science developed almost entirely within a period of relative climate stability. Successfully meeting the challenges of forest conservation and sustainable management in an era of accelerating climate change will require certain forest science, policies, and practices that do not yet exist, and will have to be developed.

Vulnerability assessments that encompass terrestrial and aquatic habitat, biodiversity, vegetation management, hydrology, and forest road systems are essential to understanding the potential effects of climate change on forest ecosystems as a whole, and the implications for the range of environmental, economic, and social values and services that forests provide.

This new science cannot be developed in isolation. In order for this new knowledge to be readily useful and to make a different on the ground where it counts, it must be developed in the context of actual resource management planning and decision making (USDA 2008; USDA 2010). Budgets and human resources will never be unlimited for managers of either public or private forest lands. Resource managers need decision support tools that allow them to integrate vulnerability assessments with action strategies to establish reasoned priorities and make the best-informed decisions possible (Peterson and others 2011; Halofsky and others 2011). Resource managers must be able to utilize these tools to determine what they need to do differently in the future, and what existing practices will continue to be the best approach as part of an overall strategy for mitigating and adapting to climate change.

ADDRESSING INSTITUTIONAL AND POLICY CONSTRAINTS TO IMPLEMENTING ADAPTATION STRATEGIES

The objectives of the national policy conference were to (1) summarize recent advances in the scientific understanding of the projected effects of climate change on forest ecosystems and their responses to natural disturbance and human interventions, (2) describe strategies for adapting current resource management practices to sustain these evolving ecosystems and the array of social, economic, and environmental services they provide, and (3) identify opportunities to evolve the existing institutional and policy framework to support timely and effective implementation of adaptation strategies for both public and private forest lands.

The forest sector technical report for the most recent National Climate Assessment (Vose and others 2012) describes current circumstances as follows:

Significant progress has been made in developing scientific principles and tools for adapting to climate change through science-management partnerships focused on education, assessment of vulnerability of natural resources, and development of adaptation strategies and tactics. In addition, climate change has motivated increased use of bioenergy and carbon (C) sequestration policy options as mitigation strategies, emphasizing the effects of climate change-human interactions on forests, as well as the role of forests in mitigating climate change. Forest growth and afforestation in the United States currently account for a net gain in C storage and offset approximately 13 percent of the Nation's fossil fuel CO_2 production. Climate change mitigation through forest carbon management focuses on (1) land use change to increase forest area (afforestation) and avoid deforestation, (2) carbon management in existing forests [protecting large carbon stocks; increasing fuels treatments; increasing forest growth], and (3) use of wood as biomass energy, in place of fossil fuel or in wood products for carbon storage and in place of other building materials. Although climate change is an important issue for management and policy, the interaction of changes in biophysical environments (e.g., climate, disturbance, and invasive species) and human responses to those changes (management and policy) will ultimately determine outcomes for ecosystem services and people.

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 [emphasis added]. 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 foundation for managing forest ecosystems in the context of climate change as soon as possible will ensure that a broad range of options will be available for managing forest resources sustainably (Paquette and Messier 2010; Victor 2005; Sedjo and Botkin 1997).

The conference examined existing constraints to timely and effective implementation of adaptation strategies, and steps that can be taken in the near term to accelerate the evolution of policies and institutional frameworks to address these constraints. These include:

Education and awareness. There is a lack of public awareness of how climate change affects natural resources influences the level and nature of adaptation by public institutions. The lack of experience and understanding of climate science by resource managers can lead to low confidence in taking management action in response to climate threats (GAO 2007); similar limitations through the chain of supervision and decision making constrain appropriate efforts (GAO 2009).

Monitoring and adaptive management. Adaptive management has been understood as a core component of ecosystem management for more than two decades, but climate change is necessitating and even more central role for real-time monitoring, reporting, and incremental adjustments in land and resource management plans and activities (Peterson and others 2011; Swanston and Janowiak 2013). The effectiveness of adaptive management on public lands as well as private has been limited by the weak institutional framework for monitoring, by inadequate funding and by lack of analyst capacity.

Policy and planning. Public agencies and private organizations alike are constrained by hierarchies of laws, regulations, and policy direction developed before the effects of climate change were recognized or well understood; they are based on the assumption of stable and predictable climate, and thus provide limited authority for resource managers to accommodate the dynamics of climate change. Forest management organizations of all kinds confront operational challenges in working at spatial and temporal scales compatible with climate change adaptation.

Budget and fiscal barriers. Significant additional funding will be needed for: education and training; development of science-management partnerships; vulnerability assessments; and development of adaptation strategies. Collaboration across organizational as well as geographic boundaries, leveraging of institutional capacities, and other innovative solutions will be needed to address the budget challenge.

The characteristics that define the Anthropocene—the Age of Man—are about more than just the changing climate. It is about more than 7 billion people occupying virtually every biome on the planet, and human infrastructure that influences both our ability to mitigate climate change, and to adapt to it (Zalasiewicz and others 2010). We know that climate change is already affecting forests around the world, and strongly influencing their ability to provide the environmental, economic, and societal values and services on which society depends. These effects are already evident today in extraordinarily destructive wildfires and floods, unprecedented epidemics of insects and pathogens, and other manifestations of forest ecosystems already under high levels of environmental stress. Based on the combined results of numerous climate models, it is expected that these climate changes will strengthen and accelerate over the next several decades and perhaps centuries.

Significant progress has been made in developing the science and management approaches needed to understand, prepare for, and ultimately to adapt to these changes. There is much more we need to learn, but we know enough now to begin taking decisive actions on the ground to implement adaptation strategies on both public and private forest lands. The bottlenecks we are now encountering are not based so much on the limitations of our science as on limitations in the policies and the existing institutional framework within which forestry is practiced.

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