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Introduction

Forest Conservation and Management in the Anthropocene

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Throughout Earth's history, its climates have been changing and its biotic systems have mutated, migrated, and otherwise adapted as tectonic shifts have reconfigured the continents and as polar ice caps have ebbed and flowed across the latitudes through glacial cycles. There is substantial evidence that climatic changes that in the past have taken place over the course of millennia are now happening in a matter of decades, and that these rapid transformations are human caused. That has led researchers to coin a new term for this era, the Anthropocene—the Age of Humans. These accelerated alterations in climate challenge the ability of 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 from 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.

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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. "Rapid climate change is the defining conservation issue of our generation," notes a report by a group of federal natural resource management agencies and nonprofit organizations. "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 et al. 2011). Traditional wildlife and biodiversity conservation strategies have relied heavily on the establishment of reserves and other protected areas to conserve habitat, but as climate changes, optimal habitat zones shift to different places on the landscape as well. So a basic question that has arisen for conservation biologists is whether protected areas that are fixed and static on the landscape can still play a useful role in protecting plant and animal species that are in the process of relocating.

As Gary Tabor and his coauthors note in chapter 13, landscape-scale habitat conservation strategies, originally developed to address the issue of habitat fragmentation, are now being pressed into service as climate adaptation strategies. Corridors and linkages that can connect habitat across several degrees of latitude are becoming critically important to facilitate the emigration of some plant and animal species and the immigration of others. However, some species within a given ecological community are more mobile than others: some are able to migrate and others are left behind, disassembling existing communities of interdependent species. At the same time, a region will experience the immigration of mobile species from elsewhere, developing species assemblages that may never have existed before. How to regard these "novel ecosystems" is a topic of considerable ongoing debate among conservation biologists. From one perspective, many of these novel ecosystems are highly biologically productive and may also exhibit a high level of species diversity, so they may represent a significant biodiversity resource in themselves. This migratory process, according to Tim Caro and his coauthors (chapter 6), will increase the importance of large protected areas with well-buffered interior regions that are more resistant to immigration by species from distant locales.

This still leaves the question of whether something can be done to minimize the emigration of species from such reserves and the dismantling of the existing ecological community. Anderson and Johnson (chapter 9) describe characteristics that can help scientists define biological and geological characteristics that allow the identification of "resilient sites" that tend to resist the influence of climate change and hold their ecological communities intact. These sites tend to have certain characteristics of geology, soils, and topography. Identifying, mapping, and then protecting a sufficient number of these resilient sites across large landscapes can be an important component in a comprehensive, portfolio approach to adapting biodiversity conservation to the effects of climate change.

There are significant additional challenges associated with actually implementing such a strategy on large landscapes predominantly characterized by private ownership and comprising many small tracts. These tracts are typically managed for objectives as diverse as the private owners themselves, who may or may not understand or share a commitment to biodiversity conservation. Once again, large landscape conservation strategies originally developed for other purposes can be repurposed to help achieve biodiversity conservation objectives in regions characterized by mixed public-private or predominantly private ownerships.

One of those key complications is the complex relationship between climate change, water, and forests, and its direct, indirect, and induced effects. Regions that experience prolonged drought and elevated temperatures will obviously face challenges resulting from lower precipitation and higher evapotranspiration, and areas that depend upon high-elevation snowpack to maintain late-season flows will more often find themselves in extreme water emergencies. This will be a major issue for aquatic habitat, especially when combined with higher water temperatures and lower dissolved oxygen levels. Cold-water species such as West Slope cutthroat trout and Dolly Varden (bull trout) may face particular environmental stress, and localized populations unable to migrate to more suitable habitat may die out (Williams et al. 2009; Wenger et al. 2011).

Intact forests can mitigate all of these influences on water supply, quality, and temperature, but as forests themselves begin to show the effects of climate change their ability to do so will be sharply reduced. Forests are remarkably efficient at absorbing precipitation, storing it, and gradually releasing it as streamflow. Forests in higher elevations can be managed for optimal snow interception by maintaining crown cover that is open enough not to intercept too much snow, where it will sublimate back into the atmosphere, but closed enough to provide shade to the snow that does penetrate to the ground, slowing spring snowmelt and helping to maintain late-season flows. Climate-induced environmental stress that results in tree mortality from drought, insects, or disease diminishes each of these functions (Allen et al. 2010).

The most extreme effects are from wildfire. Extensive crown fires in Colorado's Front Range in 1996 and 2002 caused major damage to the Strontia Springs and Cheesman Reservoirs, threatening the municipal water supply for Denver and communities along the Front Range. A decade later, local water authorities were still spending millions of dollars annually for additional water treatment and the removal of tons of sediment and debris from check dams installed upstream from these reservoirs after the fires. By leaving slopes barren of trees and other vegetation, and reducing the ability of soils to absorb water during major storms, recent wildfires in Colorado, California, and other parts of the western United States have been shown to contribute to flash flooding for many years subsequent to the fire itself (Cannon et al. 2008).

The decisive steps that Denver took to reduce the likelihood of wildfire damage to its other reservoirs provide a model that other cities and communities are taking up, especially as the changing climate is raising the stakes. Denver Water and several water authorities serving other Front Range communities sought and received permission to add a small surcharge to customers' regular water bills, creating a fund that was used to accomplish hazardous fuels treatments and forest health thinnings on forest lands upstream from municipal reservoirs. Most of these lands are national forests, and Denver Water and the US Forest Service subsequently entered a cooperative agreement in which each party would contribute more than $16 million to accelerate treatments on thousands of acres of forest (Denver Water Authority 2013).

The lessons learned in Denver were not lost on other western communities surrounded by fire-prone forests that, should a wildfire occur, would cause substantial damage to the local water supply. Laura McCarthy (chapter 11) analyzes one such proactive initiative, a study that The Nature Conservancy conducted for the city of Santa Fe, New Mexico. The study estimated the economic losses should a major fire occur in the city's primary watershed on the Santa Fe National Forest and demonstrated that the probability of such a fire could be significantly reduced through hazardous fuels treatments and forest health thinnings. The cost for these interventions would be a fraction of the projected damages. As a result, voters approved and the city enacted a modest surcharge on local water customers, and used this to create a water fund that underwrites the necessary forest management activities.

In regions of the country where the changing climate is expected to bring higher levels of precipitation and more of it in the form of extreme storm events, intact forests are becoming a high-value asset. Hurricane Irene in 2011 dumped an extraordinary volume of rain on the Mid- Atlantic states and New England in a very short period, and satellite photos from a few days after the storm showed the Susquehanna River in full flood stage, choked with sediment and debris, which was flushing into Chesapeake Bay and turning its northern portion an opaque brown. Municipal water supplies were interrupted for nearly two weeks in Harrisburg, Pennsylvania, and other communities drawing their drinking water from the Susquehanna, and power plants drawing cooling water from the river were either shut down or operating at reduced output (Water Research Foundation 2012).

In the same satellite photo, the next major watershed to the east, the Delaware River, can be seen running clear and blue, sparkling in the sunlight. One major reason for this is the fact that the headwaters of the Delaware River are roughly 80 percent forested, whereas forest cover has been reduced to less than 40 percent in the headwaters of the Susquehanna. There is a major effort now under way to restore thousands of acres of riparian forest in the upper Susquehanna watershed—a valuable initiative but one that will take years to begin having a meaningful effect. Meanwhile the upper Delaware River watershed continues to lose forest cover at an average of more than 100 acres (40 ha) a week. The Pennsylvania, New York, and New Jersey counties that come together in the upper Delaware are the fastest developing counties in their respective states. Will Price and Susan Beecher (chapter 14) explain the collaborative efforts to create the Common Waters Fund, an innovative mechanism developed to give private forestland owners a financial incentive to conserve their forest, and to manage it in ways that will enhance its watershed-protection capabilities.

But most of the communities and businesses downstream on the Delaware have yet to be convinced that it is in their interest to invest in keeping the forested headwaters intact. Water supply and water quality have been good recently, and many water users seem willing to take a chance that the continued loss of forest cover to development will not have any significant impact on them. Yet the growing prospect of more extreme storm events like Hurricanes Irene and Sandy may be changing that benefit/cost ratio. The economic impacts of a severe flood event on the Delaware would be enormous, and the forested headwaters play an important role in flood mitigation and buffering the effects of extreme storm events. Unlike the Rio Grande or the Susquehanna, whose headwaters forests are in need of costly restoration, the headwaters forests of the Delaware simply need to be maintained as they are. Currently there are more private forestland owners in the upper Delaware waiting to participate than there is money in the Common Waters Fund to enlist them—and the development pressure continues. As the effects of climate change become more pronounced, it will be clear that what the headwaters forests provide in terms of water supply, water quality, flood mitigation, and buffering extreme storm events is well worth the modest investment needed to keep them intact.

A different set of challenges confronts the wood products industry. Certain high-value hardwood species, for example, are likely to become more susceptible to exotic pests and pathogens such as the emerald ash borer (*Agrilus planipennis*), Asian long-horned beetle (*Anoplophora glabripennis*), and Sudden Oak Death (*Phytophthora ramorum*). Hopefully this will not have the impacts that the chestnut blight (*Cryphonectria parasitica*) has had on the American chestnut (*Castanea dentata*) that once dominated the eastern hardwood forests, but it is not something that even the best scientists are able to predict with confidence.

In the dry conifer forests of the Southwest and central Rockies, native forests have already been fundamentally altered by widespread mortality from the mountain pine beetle (*Dendroctonus ponderosae*) and other naturally endemic species, the result of a perfect storm in which warmer winters have fostered the survival of extraordinarily high populations of bark beetles and other agents, and drought stress has drastically reduced the ability of trees to resist and survive insect attacks. Even in fire-adapted forest types such as Ponderosa pine (*Pinus ponderosa)*, the unnatural and all-consuming crown fires that often follow leave vast areas of forests with no means to regenerate and restore themselves. Many areas, especially in the American Southwest, will not return to forest within the foreseeable future and are even now in the process of converting from forest ecosystems to grassland or shrubland ecosystems. As Craig Allen (chapter 4) and Anthony L. Westerling and others (chapter 3) note, this is profoundly changing water regimes, wildlife habitat, and biodiversity across immense areas of forests, challenging local communities as well as resource managers to quickly develop new strategies for resistance, resilience, or the readjustment of their future expectations in light of climate change.

In the intensively managed forests in regions such as the US South and Pacific Northwest, there seems to be a sense that the short rotations typical of commercial plantation forests will allow forest managers to stay ahead of the accelerating pace of climate change. Research is producing more drought-resistant varieties of important commercial tree species, which presumably will replace existing forests as they are harvested. Genetic modification may offer opportunities to attune certain tree species to new and evolving climate characteristics, but the acceptance of widespread use of such techniques is far from certain. A strategy based simply on more frequent opportunities to replace existing trees may not fully account for other climate-related effects such as more intense storms like Hurricanes Katrina and Hugo that can destroy millions of acres of forest very quickly. Prolonged drought and elevated temperatures also reduce resistance to pests such as bark beetles, which can still kill large expanses of forest in a relatively short time. All of these factors contribute to increases in wildfire activity, a trend that is already being documented even in the South (Vose et al. 2012).

Getting a handle on some of these trends requires the development of vulnerability assessments that encompass terrestrial and aquatic habitat, biodiversity, vegetation management, hydrology, and forest road systems. As Jessica Halofsky and her colleagues argue (chapter 12), these tools are also 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. These authors are optimistic that climate change can be mainstreamed in the policies and management of the Forest Service and other federal agencies by the end of this decade by considering climate change as one of many risks to which natural resources are subjected, and by considering adaptation as a form of risk management.

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 et al. 2011; Halofsky et al. 2011). Resource managers must also 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. The catch: budgets and human resources will never be unlimited for managers of public or private forest lands, so managers will need to be as adaptive and resilient as the forested landscapes they manage.

As early as 2020, US forests are expected to decline in their ability to serve as the nation's largest terrestrial "carbon sink." Today, these forests store enough carbon to absorb roughly 14 percent of total US greenhouse gas emissions. Before 2050, this very significant carbon offset could drop to zero, and the nation's forests would themselves become net sources of carbon emissions (USDA Forest Service 2012a). As Westerling et al. (chapter 3), Allen (chapter 4), and Stephens (chapter 5) point out, this is largely due to two factors: the increasing size, frequency, and intensity of wildfires, as most of the western United States continues on a trend of elevated temperatures and extended drought, and the continuing loss of private forests for development. It is still possible to avoid or at least mitigate this projected future, but it will require decisive actions and a substantial strengthening of current conservation and sustainable forest management efforts to change the trajectory US forests are now following. These actions include:

1. Increase afforestation and decrease deforestation:
   - Stem the conversion of forests to development and other land uses; the loss of forests and open space to development was recently estimated at approximately 6,000 acres (2,400 ha) per day, or roughly 4 acres (1.6 ha) per minute.
   - Increase the resistance and resilience of dry forests in the western United States to minimize the conversion to grassland ecosystems in the wake of major insect or disease outbreaks and wildfires.
2. Increase substitution of wood for fossil fuels in energy production, and for other building materials to maximize long-term carbon storage:
   - Increased biomass energy from the current 2 percent of US energy use to 10 percent would prevent the release of 130–190 million metric tons/

year of carbon from fossil fuels (Perlack et al. 2005, Zerbe 2006); commitment to conservation and reforestation of harvested sites is critically important to this net gain.

- Use of 1 metric ton of carbon in wood materials in construction in place of steel or concrete can result in 2 metric tons in lower carbon emissions, due to lower emissions associated with production processes (Sathre and O'Connor 2008, Schlamadinger and Marland 1996). Using wood from fast-growing forests for long-lived wood products and bioenergy can be more effective in lowering atmospheric carbon than storing carbon in the forest, where increased wood production is sustainable (Baral and Guha 2004, Marland and Marland 1992, Marland et al. 1997).

3. Manage carbon stocks in existing forests:
   - Increase forest carbon stocks through longer harvest intervals and protect forests with high biomass.
   - Manage forest carbon with fuel treatments: carbon emissions from wildland fires in the coterminous United States have averaged 67 million metric tons/year since 1990 (US Environmental Protection Agency 2009, 2010). Stand treatments intended to reduce fire intensity, especially crown fires that result in near-total tree mortality, have the potential to significantly reduce carbon emissions.

Integrating these domains of science and forging a new interdisciplinary science of the Anthropocene cannot be developed in isolation. This book is intended to break down some of these barriers and open up necessary discussions among scientists, land managers, policy makers, and citizens. For this new knowledge and engaged conversations to make a difference on the ground, it must be developed in the context of actual resource management planning and decision-making (USDA 2008; USDA 2010).

The objectives of this book are 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 public and private forest lands.

This book examines 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:

- Public awareness. There is a lack of public awareness of how climate change affects natural resources. and this information gap influences the level and nature of adaptation by public institutions.
- Resource manager awareness. 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 an even more central role for real-time monitoring, reporting, and incremental adjustments in land and resource management plans and activities (Cleaves and Bixler, chapter 16; Peterson et al. 2011; Swanston and Janowiak 2012). 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 the 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 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 our ability to mitigate climate change and to adapt to it (Zalasiewicz et al. 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. As Curt Stager notes (chapter 1), the combined results of numerous climate models suggest 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, however, *Forest Conservation in the Anthropocene* is an important first step in developing the ideas that will drive the conversation—and the resulting policy-making—forward. But we know enough now to begin taking decisive actions at the local, regional, and national level to implement adaptation strategies on public and private forest lands. As noted at the end of this book (Cleaves and Bixler, chapter 16; Shaffer, chapter 15), 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.