Chapter 10
Research and Assessment in the Twenty-First Century

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10.1 Improving the Accuracy and Certainty of Climate Change Science

We have heard more than one natural resource manager remark that keeping up with scientific information on climate change is like drinking from a fire hose! The sheer volume of scientific literature makes it challenging to sort through and evaluate evolving concepts and interpretations of climate change effects, as suggested by the fire hose simile. This proliferation of scientific information is providing a foundation for quantifying forest-climate relationships and projecting the effects of continued warming on a wide range of forest resources and ecosystem services. Certainty about climate change effects and understanding of risk to biosocial values has increased as more evidence has accrued.

The recent expansion in scientific analysis of the effects of climate on ecological disturbance has provided empirical data on how wildfire, insects, and other disturbances respond to warmer climatic periods. However, more information is needed on the interaction of ecological disturbances and other environmental stressors, especially for large spatial and temporal scales. Thresholds for climatic triggers of

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environmental change are poorly understood, and although simulation modeling can suggest how and when thresholds might be exceeded, additional empirical data are needed to confirm thresholds, and research is needed to improve the accuracy of process modeling at different spatial scales. Our understanding of stress complexes in forest ecosystems needs to be expanded to additional ecosystems, including better quantitative descriptions of stressor interactions.

Despite a century of ecological research on human-altered landscapes, our ability to interpret ecological change in the context of human land use and social values is incomplete. Documenting the effects of land use at small spatial and temporal scales is relatively straightforward, but we need to improve our ability to quantify the effects of land use on climate-ecosystem relationships at large spatial and temporal scales. Inferences about climate change effects will be more relevant if various land uses, including evaluation of future alternatives, are considered in a context that incorporates humans, rather than excluding them or considering their actions to be "unnatural" or negative. A framework for quantifying ecosystem services is needed that can be transported across different organizations and that includes a wide range of biosocial values.

Several general scientific issues also need additional focus. First, the value and appropriate interpretations of empirical (statistical) models versus process (mechanistic) models for projecting climate change effects warrant a rich discussion within the scientific community. Conceived from different first principles (e.g., assumed equilibrium [empirical] vs. dynamic [process] climate-species relationships), output from these types of models often differs considerably or is difficult to reconcile because of different assumptions, spatial resolution, and hierarchical levels (e.g., species vs. life form). Resource managers and other users of model information cannot be expected to understand the workings of complex simulation models. Therefore, it is incumbent on the scientific community to do a better job of stating model assumptions, sensitivities, and uncertainties, and to clearly indicate the appropriate contexts for interpreting and using model output.

Second, the direct effects of elevated carbon dioxide (CO_2) on forest ecosystems need to be clarified. Most existing inferences are based on experimental treatments on seedlings and small trees, and on output from simulation models that assume certain types of growth responses. Including CO_2 stimulation (or not) can drive the output of vegetation effects models to such an extent that this factor alone determines the direction of simulated response to climate. A unified effort by scientists to resolve the significant challenges in scaling and interpreting data on direct CO_2 effects (especially in mature forests) is needed to quantify future vegetation productivity and competition among plant species.

Third, effects models that can project multi-centennial patterns of vegetation distribution, disturbance, and biogeochemical cycling dynamics would provide longer term scenarios for planning and policy decisions. Most output from climate change effects models extends to 2100, the limit of projections for most global climate models. This may be sufficient for short-rotation (25–50 years) production forestry, but only scratches the surface for forest ecosystems in which trees can survive for hundreds of years.

We recommend that future research:

- Develop and implement new approaches to understand the effects of elevated CO_2 in mature and diverse forests. The knowledge gained from free-air CO_2 enrichment (FACE) experiments provided a solid understanding of short-term CO_2 responses in young forest stands for a limited number of species (Norby and Zak 2011). However, additional information is needed, including at least some evaluation of whole mature forest stands and physiological measurements of individual trees within stands. Studies in different forest ecosystems are needed to provide a broad perspective on how elevated CO_2 will affect forest productivity and other factors.
- Develop a standard approach for tracking carbon (C) dynamics in different forest ecosystems over space and time. This will improve ecological knowledge and provide consistent input to C accounting systems. It will be important to ensure that C measurements and C accounting can be used in a straightforward manner by resource managers.
- Identify appropriate uses and limitations of remote sensing imagery for detecting the effects of climatic variability and change in forest ecosystems. Remote sensing data from a variety of platforms are now more accessible than in the past, although these data can generally be analyzed and interpreted by only a few specialists. If tools to access, analyze, and help interpret the most reliable and relevant remote sensing data were easier to use, resource managers could obtain timely feedback on forest stress on a routine basis.
- Determine which ongoing and long-term forest measurements are useful or could be modified for tracking the effects of climate change. This may be a small subset of the monitoring data currently being collected on biophysical characteristics of forest ecosystems. Building on existing infrastructure for monitoring will be more efficient than developing new monitoring programs, thus extending time series of measurements taken with established protocols.
- Identify standard approaches for evaluating uncertainty and risk in vulnerability assessments and adaptation planning. Straightforward qualitative and quantitative frameworks will advance the decision making process on both public and private lands.
- Evaluate recently developed processes and tools for vulnerability assessment and adaptation planning to identify which ones are most effective for “climate smart” management on public and private lands. The availability of straightforward social and logistic protocols for eliciting and reviewing scientific information and stakeholder input will make climate change engagement more effective and timely.

It will be especially important to frame the above topics at the appropriate spatial and temporal scales in order to provide relevant input for different climate change issues. In addition, climatic data at different spatial scales need to be matched with applications at different spatial scales to be relevant for climate smart management (Wiens and Bachelet 2010). Despite the value of downscaled climatic and effects data, it should be recognized that the appropriate grain and extent of these data differ by resource (hydrology vs. vegetation vs. wildlife) and resource use (timber management vs. water supply vs. access for recreation). Sharing of information and experiences within and among organizations involved in climate change activities will facilitate incorporation of robust methods and applications across any particular landscape.

10.2 Toward an Ongoing National Assessment

Are we prepared to confront and respond to climate-related forest changes within the context of forest management? The answer lies in our ability to recognize potential loss, quantify risk, examine options, identify tradeoffs, anticipate rare but high-consequence events, and invest commensurate with risk. The challenge before us will require new tools, information, and technology, as well as the experience of resource managers.

As noted above, knowledge gaps exist in our ability to project how forest ecosystems will respond to the direct and indirect effects of climate change. Although ongoing research is addressing some of these knowledge gaps, the complexity of some scientific issues means that many management and policy decisions will continue to be based on imperfect information.

A long-term, consistent process to evaluate climatic risks and opportunities is needed to provide information that supports decision making at various levels. To that end, one objective of the 2014 U.S. National Climate Assessment (NCA) is to improve climate assessment capabilities in an integrated fashion. The current NCA approach is more focused than past climate assessments in supporting adaptation and mitigation, and in evaluating current scientific knowledge relative to climate effects and trends. The U.S. Global Change Research Program and NCA are working toward establishing a permanent national assessment capacity.

Natural resource assessment will be more powerful if the work of stakeholders and scientists across the United States is integrated in an ongoing and continuous process. It will be especially important to track specific climatic stressors, observe and project effects of climate change within regions and sectors, and rapidly deliver data and Web-based products that are relevant for decision making. Ongoing assessment of the effectiveness of mitigation and adaptation practices will also be needed. This is no small task. A truly successful national assessment process will require participation by federal, state, and local government agencies, nongovernmental organizations, academia, and tribal and private interests.

Several emerging issues identified in previous chapters urgently need to be incorporated in national and regional monitoring systems. Ecological disturbance, invasive species, urban forests, forest conversion to other uses, fragmentation of forest habitat, and C cycling are all dynamic entities for which timely monitoring is needed to inform effective adaptation options. Biosocial monitoring is also needed to track the effects of climate change on ecosystem services, human health, water and watersheds, energy and bioenergy, and forest industry.

Identifying areas where forests are most vulnerable to change (i.e., have low resistance and resilience) and where the effects of change on ecosystem services will be greatest is a significant challenge for resource managers. One would expect forest ecosystems and species near the limits of their biophysical requirements to be vulnerable, but the complexities of fragmented landscapes and multiple stressors are likely to alter response thresholds. Under these conditions, management approaches that anticipate and respond to change by guiding development and adaptation of forest ecosystem structure and function will be needed to sustain desired ecosystem services across large landscapes.

Some periodic assessments of forest resources have been implemented in the United States. For example, sustained efforts such as the Forest and Rangeland Renewable Resources Planning Act (RPA) assessment and periodic efforts such as the National Sustainability Report (USDA FS 2011) provide integrated national-scale information. The U.S. Forest Service Forest Inventory and Analysis (FIA) program measures forest growth and related parameters using consistent protocols at 10-year intervals across the nation. FIA is primarily a large-scale inventory, and climate change would need to have a significant effect on net forest growth for FIA data to detect it. However, these data can be used to calculate forest C flux approximated as a change in forest stocks over time. Accounting for C and managing ecosystems raises significant questions because of uncertainty about how C pools will change with climate. Coordination of remotely sensed data with on-the-ground data from inventory and monitoring is a powerful approach for quantifying climate-related trends in resource conditions—inferences are more convincing when multiple lines of evidence are available.

The most recent RPA assessment (USDA FS 2012) summarizes current conditions, trends, and forecasts for the next 50 years. Recent changes to the assessment include (1) presenting conditions, trends, and forecasts in a global context, (2) utilizing three global climate models and multiple emission scenarios (A1B, A2, and B2), and (3) integrating the analysis with socioeconomic factors (e.g., wood product markets and the price of timber). The RPA assessment indicates that forest area in the United States peaked at 253 million ha in 2010 and will decline through 2060 to between 243 and 247 million ha. Product markets, population, income, and climate all interact to determine future forest area, biomass, and forest C. Climate will influence the outcomes, and although significant variation exists across potential climate futures, it is still small relative to human factors in the short run.

10.3 Improving Risk Assessment

Many organizations are working to identify potential climate change vulnerabilities and effects, along with adaptation options to address them, but disparate analyses and interventions need to be incorporated in the context of risk assessment. A risk-based framework (see Chap. 9) needs to be further developed and agreed upon as a standard means for evaluating the consequences and likelihood of climate change effects. The NCA provides a simple set of guidelines for risk assessment (Yohe and Leichenko 2010), based on the risk and uncertainty framework developed by the Intergovernmental Panel on Climate Change (Moss and Schneider 2000). Risk assessment is now being incorporated in several national and state climate change management efforts. For example, all four National Research Council panel reports of "America's Climate Choices" incorporate this framework, as does the draft Adaptation Plan for the United States.

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 it. Risk assessment should generally be specific to a particular region and time period, modified by an estimate of confidence in projections of climate change effects. Refining and expanding existing risk management frameworks will provide a consistent approach for addressing climate change vulnerabilities, so that risk can be evaluated iteratively over time as scientific information is updated.

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