Chapter 1

Introduction

David L. Peterson and James M. Vose[1]

Projected changes in climate (temperature and precipitation means and extreme events), increased atmospheric carbon dioxide (CO_2), and increased nitrogen deposition are likely to affect U.S. forests throughout this century. Effects will be both direct (e.g., effects of elevated CO_2 on forest growth and water use) and indirect (e.g., altered disturbance regimes), and will differ temporally and spatially across the United States. Some of these effects may already be occurring. For example, large insect outbreaks and large wildfires during the past decade (Bentz et al. 2009, Turetsky et al. 2010) are a wake-up call about the potential effects of a rapidly changing climate on forest ecosystems. Individually and in combination, these two major disturbance phenomena are reshaping some forest landscapes and may be causing long-term, possibly permanent changes in forest structure, function, and species composition (Hicke et al. 2012, McKenzie et al. 2004). Combined with other stressors, such as invasive species and air pollution (McKenzie et al. 2009), and a legacy of fire exclusion and other land management activities, maintaining resilience and restoring forest ecosystems in the face of climate change will be a major challenge for the 21st century and beyond (Peterson et al. 2011).

In this document, we provide a scientific assessment of the current condition and likely future condition of forest resources in the United States relative to climatic variability and change. This assessment, which is conducted periodically by the U.S. Global Change Research Program as a component of a broader assessment of the effects of climate change on natural resources (U.S. Global Change Research Program 2012), is scheduled to be completed in 2013. The most recent assessment of the forest sector (Ryan and

Archer 2008) provides a foundation and point of departure for this document. We focus on the latest observations of effects of climatic variability and change in forest ecosystems, supported by scientific literature, with emphasis on issues and solutions relevant for sustainable management of forest resources.

It is difficult to conclude whether recently observed trends or changes in ecological phenomena are the result of human-caused climate change or climatic variability. Regardless of the cause, we emphasize the response of forest resources to climatic patterns observed over the past few decades because they are similar to climatic phenomena expected for the rest of the 21st century. Compared to most of the 20th century, these more recent patterns are associated with periods of warmer temperature throughout the United States, and to multiyear droughts (low soil moisture) in arid and semiarid regions of the Western United States and many areas of the Eastern United States (Karl et al. 2009). For example, Breshears et al. (2005) concluded that dieback of pinyon pine (*Pinus edulis* Engelm.) in the Southwestern

[1] **David L. Peterson** is a research biological scientist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, 400 N 34th Street, Suite 201, Seattle, WA 98103; **James M. Vose** is a research ecologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Center for Integrated Forest Science and Synthesis at North Carolina State University, Department of Forestry and Environmental Resources, Campus Box 8008, Raleigh, NC 27695.

United States was caused by "global-change type drought." If extended drought will indeed be more common in the future, then it is reasonable to infer that this type of dieback will also be more common. "Global-change type" climatic phenomena provide a reasonable context for projecting the effects of climate change on forest ecosystems.

In this document, we develop inferences from small-scale experiments (e.g., soil warming or CO_2 enrichment studies) and time series of natural resource data when available, while recognizing the challenges and uncertainties of scaling small-scale and site-specific studies in time and space (Peterson and Parker 1998). We also use the results of simulation modeling to project the effects of climate change on species distribution and abundance, ecosystem processes, ecological disturbance, and carbon dynamics. The results of both empirical (statistical) and process-based (mechanistic) models are presented, and we emphasize that these results are projections (proposed or calculated), rather than predictions (forecast or foretold about the future). Trends established by empirical data, combined with results from robust modeling, are a good combination on which to base inferences about climate change effects (e.g., Araújo et al. 2005). In this document, climate change effects are rarely projected beyond 2100, the limit for most current global climate models and emission scenarios (Solomon et al. 2007). We have high confidence in projections through the mid-21st century, beyond which agreement among global climate models diverges.

Forest ecosystems are inherently resilient to variability in climate at time scales ranging from daily to millennial. For example, forest species distribution and abundance have shifted over long time scales by responding individually to variability in temperature, precipitation (Brubaker 1986), and climatic influences on wildfire and other disturbance regimes (Prichard et al. 2009, Whitlock et al. 2008). Gradual changes in mean climate or atmospheric environment produce gradual changes in ecosystems. However, a rapid increase in temperature will increase the number of extreme climatic periods (e.g., extended droughts), leading to more frequent and intense ecological disturbances, which in turn lead to rapid change in the composition and dynamics of forests (McKenzie et al. 2009). Therefore, this assessment often focuses on extreme events and ecological disturbance, because these phenomena usually produce faster, larger, and more persistent changes than does a gradual increase in temperature.

Although the short-term effects of the El Niño-Southern Oscillation on natural resources have been well documented, the effects of dominant modes of climatic variability (Atlantic Monthly Oscillation, Pacific Decadal Oscillation, Pacific North American pattern) provide a better understanding about the potential effects of climate change, because periods of warmer (and cooler) and drier (and wetter) conditions are experienced over two to three decades at a time. For example, in some areas of the Western United States, the warm phase of the Pacific Decadal Oscillation is associated with more area burned by wildfire than in the cool phase (Hessl et al. 2004, Schoennagel et al. 2007). Studies of longer term modes of climatic variability thus provide a window into the nature of a permanently warmer climate, including quantitative relationships among temperature, precipitation, and area burned, on which projections of the effects of different climatic conditions can be based.

Forests that experience frequent disturbance often have characteristics that enhance their capacity to survive disturbance events (resistance) or facilitate recovery after disturbance (resilience) (Millar et al. 2007). Despite this inherent capacity, current thinking suggests that the rapid pace and magnitude of climate change will exceed the resistance and resilience capacity of many forests, and novel ecosystems without historical analogs will develop (Hobbs et al. 2009, Williams and Jackson 2007). A significant challenge for resource managers is to identify areas where forests are most vulnerable to change (i.e., have low resistance and resilience) and where the effects of change on critical ecosystem services will be greatest. Among the most obvious locations for vulnerable forest ecosystems (and species) are those near the limits of their biophysical requirements (Parmesan and Yohe 2003). However, the complexities of fragmented landscapes and multiple co-occurring stressors are likely to change response thresholds in many forest ecosystems (Fagre et al. 2009), with outcomes that may be unpredictable and unprecedented (Anderson et al. 2009, Scheffer et al. 2009). Under these conditions, traditional approaches to forest management that focus on historical conditions or protection of rare species or communities are likely to fail. Management approaches that instead anticipate and respond to change by guiding development and adaptation of forest ecosystem structures and functions will be needed to sustain desired ecosystem services and values across large landscapes and multiple decades (Millar et al. 2007, Seastedt et al. 2008). In this document, we discuss new management approaches along with specific tools and case studies. Uncertainty and risk are frequently discussed in this document, as mandated by general guidance for the National Climate Assessment. Important sources of uncertainty include short time series of climatological and forest effects data, limited spatial extent of many types of measurements, lack of understanding of complex ecological processes, and simulation models that cannot accurately represent a wide range of ecosystem dynamics. Risk is generally associated with the likelihood of exposure or effects at specific points in time, combined with the magnitude of the consequence of a particular biophysical change (Mastrandrea et al. 2010, Yohe and Oppenheimer 2011). Risk is inherently associated with human judgments and ranking (e.g., high, medium, low) and human values related to ecosystem services and perceptions (good vs. bad). When clearly articulated, in either qualitative or quantitative terms, uncertainty and risk are useful concepts for natural resource managers, decision-makers, and policymakers (Spittlehouse and Stewart 2003). Incorporating risk into discussions of climate change effects is relatively new for the forest resources community, but we are optimistic that doing so will improve our ability to apply climate change science to the management of forest ecosystems, including the development of adaptation options.

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