FOREST HEALTH IN NORTH AMERICA: SOME PERSPECTIVES ON ACTUAL AND POTENTIAL ROLES OF CLIMATE AND AIR POLLUTION

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Abstract. The perceived health of forest ecosystems over large temporal and spatial scales can be strongly influenced by the frames of reference chosen to evaluate both forest condition and the functional integrity of sustaining forest processes. North American forests are diverse in range, species composition, past disturbance history, and current management practices. Therefore the implications of changes in environmental stress from atmospheric pollution and/or global climate change on health of these forests will vary widely across the landscape. Forest health surveys that focus on the average forest condition may do a credible job of representing the near-term trends in economic value while failing to detect fundamental changes in the processes by which these values are sustained over the longer term. Indications of increased levels of environmental stress on forest growth and nutrient cycles are currently apparent in several forest types in North America. Measurements of forest coprophilological responses to air pollutants in integrated case studies with four forest types (southern pine, western pine, high elevation red spruce, and northeastern hardwoods) indicate that ambient levels of ozone and/or acidic deposition can alter basic processes of water, carbon, and nutrient allocation by forest trees. These changes then provide a mechanistic basis for pollutant stress to enhance a wider range of natural stresses that also affect and are affected by these resources. Future climatic changes may ameliorate (− CO₂) or exacerbate (+ temperature, + UV-D) these effects. Current projections of forest responses to global climate change do not consider important physiological changes induced by air pollutants that may amplify climatic stresses. These include reduced rooting mass, depth, and function, increased respiration, and reduced water use efficiency. Monitoring and understanding the relative roles of natural and anthropogenic stress in influencing forest health will require programs that are structured to evaluate responses at appropriate frequencies across gradients in both forest resources and the stresses that influence them. Such programs must also be accompanied by supplemental process-oriented and pattern-oriented investigations that make thorough tests cause and effect relationships among stresses and responses of both forests and the biogeochemical cycles that sustain them.

Key Words: air quality, physiology, growth, biotic and abiotic interactions

1. Introduction

The forests of North America are immense in both their geographical range and ecological diversity. The 326 M ha of forested land in the USA (Powell et al., 1992) and 417 M ha in Canada (NRCAN, 1998) are also a highly valuable economic resource for which maintenance of long-term productivity is a very high priority. Both actual and perceived potential responses of North American forests to atmospheric pollution during recent decades have figured strongly in policy decisions on air quality regulation that have had significant economic and ecological implications for the region. In the next century, if current increases in atmospheric CO₂ continue and projected changes in both temperature and atmospheric deposition of nitrogen (N) occur, changes in forest productivity and function will be of interest not only in terms of shifts in patterns of production, but also from the perspective of the role of forests as sinks or sources for greenhouse gases (Norby, 1998). IPCC (1998) predictions for the effects of Global Climate Change on forest health include both increased growth and range of some forests, but also an increased frequency of declining health in others in response to increased biotic and abiotic stresses associated

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with climatic warming. Evaluating forest health and forest biogeochemical functions in this more complex future environment will increasingly challenge forest scientists to measure and understand the basic processes underlying forest growth and longer term ecological health.

Perspectives on forest health and current risks posed by chemical and physical climate change differ widely within the forest community (Jenkins, 1997). These differences often stem from varying perspectives of forest values and times scales over which change is evaluated. Kolb et al. (1994) differentiated between the utilitarian view of forest health, which stresses timber production as the primary endpoint and the ecosystem perspective, which views forest health in terms of measures of longer term forest function. The latter include properties such as resilience, diversity, and the flow of carbon, water, and nutrient resources required for tree resistance to natural stresses and maintenance of biogeochemical cycles. Assessment of forest health, in fact, has many dimensions (lnnes, 1993), and at the time of our writing, there exists no universally-accepted definition of a healthy forest. O’Laughlin et al. (1994) have defined forest health as “...a condition of forest ecosystems that sustains their complexity while providing for human needs”. This definition stresses the utilitarian endpoint, which is defined in anthropocentric terms. We focus here on a more fundamental definition - A capacity to supply and allocate water, nutrients, and energy in ways that increase or maintain productivity while maintaining resistance to biotic and abiotic stresses. We, therefore, define less healthy forests as ones in which trees lose productive capacity and/or become more sensitive to environmental stresses. We should note here that unhealthy trees and stands occur naturally as a part of successional processes by which a balance between forest production, site resources, and climate are attained. In this capacity, for example, grazing insects can serve an important role in establishing a balance in nutrient flow to foliage from nutrient deficient soils (Matson and Addy, 1975). The patterns by which such changes occur however are typically spatially and temporally heterogeneous as are the localized biotic and abiotic factors that influence them.

Ecosystem response to environmental stresses, including air pollutants, is a complex, hierarchical process occurring over time scales ranging from minutes (leaf) to decades (stand). However, air pollution stresses are somewhat distinct from many other forms of environmental stress because of their regional patterns and temporal consistency with changes in air quality. Stress responses begin with sensitive individuals proceeding from branch, to tree, and then stand and ecosystem levels (Hinkeley et al., 1992) Underlying these response are process-level changes in uptake and allocation of carbon, water, and nutrient resources. We focus here on linkages between process level changes and ecosystem responses because this approach offers the best chance to understand the individual and interactive effects that will ultimately determine the utilitarian values of forest systems.

This paper summarizes recent advances in understanding of process level effects of regional air pollution on four forest types for which recent syntheses are available. These include the southeastern pine forest, eastern spruce/fir ecosystem, northeastern hardwoods, and western pine forests in Southern California (Figure 1). Our objective is to evaluate how increased understanding of forest process effects can be integrated into regional monitoring and analysis of forest health in relation to both air pollution and its interactions with other biotic and abiotic stresses that affect forests. We have emphasized primarily ozone and acidic deposition (N and S), the pollutants with the greatest potential regional impact on forests in the U.S. and Canada. Measured and potential impacts have been evaluated from the following perspectives: