Ecosystem Theory Required to Identify Future Forest Responses to Changing CO_2 and Climate

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SUMMARY

The current anthropogenic disturbances in global environmental systems require immediate study and understanding. Yet, piecemeal and applied approaches to solving these interrelated problems hold little promise because the underlying processes of environmental change and ecological response are not understood. Development of an appropriate and valid body of theory is desperately needed. The nature of certain ecosystem theory requirements is revealed by model experiments on responses by forest ecosystems to future climate and CO_2 effects. Increasing concentrations of atmospheric CO_2 potentially could generate multiple and even opposing effects on forests. Greenhouse experiments have shown that enhanced CO_2 positively affects woody seedling growth, and that these effects may also occur in saplings and mature trees under elevated CO_2 concentrations. Yet, today's close geographic correspondence between certain climate variables and forest distributions suggests that climate changes resulting from future CO_2 increases could destroy many currently existing forests. The potential response of forests to these conflicting forces was examined using a computer model of tree growth and forest stand development. The model is composed of abstractions from current ecological theory and uses knowledge of forest dynamics to simulate simultaneous changes in CO_2 and climate, and the known responses of forest stands to these variables. Model runs of several hundred years were constrained by a climate and CO_2 scenario which changed annually, as suggested by current energy use projections. Simulation results suggest that initial forest response to both climate and CO_2 changes may be minor because of tree longevity. In the long term, the positive effects on forests, simulated as CO_2 fertilization, were overwhelmed by the negative effects, simulated as drastic changes in the climatic status quo. Yet, the value of the simulations is severely diminished by weaknesses in the theoretical underpinnings of the models. Particularly (but not exclusively) constraining is the absence of a cohesive, tested theory to predict (1) forest ecosystem behavior under chronically changing environmental regulation, and (2) tree species behavior along boundaries of geographic ranges.

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INTRODUCTION

The trace gas composition of the global atmosphere continues to change in response to natural causes, such as volcanic activity, and anthropogenic ones, such as fossil fuel use. The radiatively active gases (carbon dioxide, ozone, methane, water vapor, etc.) are of particular concern. For example, carbon dioxide is transparent to short wavelengths that compose the sunlight intercepted by clouds or the earth but not to the much longer wavelengths of infrared subsequently radiated back to the sky. A "greenhouse" effect occurs when some of this infrared radiation is absorbed by CO_2 and reradiated to earth, rather than to space.

The resulting CO_2-induced climate change should generate responses in forests. Many (but not all) trees and forest communities are now, or soon may be, subjected to a different and therefore more stressful climate than that to which they were adapted as germinating seeds (Solomon and West 1985). In addition, the change in CO_2 may directly affect plant growth and forests in that enhanced atmospheric CO_2 concentrations have increased the growth of tree seedlings in greenhouse and growth chamber experiments (Lemon 1983; Oechel and Strain 1985).

Lemon (1983) and Strain and Cure (1985) have provided detailed examinations of the effects of enhanced CO_2 on photosynthesis, respiration, growth, and development of plants in greenhouse experiments. As yet, however, no research data indicate that mature trees growing in forests will be capable of taking advantage of the measured increases in dry matter production and in drought tolerance found in greenhouse herbs and woody seedlings.

Indeed, the opposite response (growth loss) could actually occur with enhanced atmospheric CO_2. Plants acclimate (cease to respond) to raised CO_2 concentrations after several days or months (Kramer and Sionit 1987; Oechel and Strain 1985), casting doubt on the long-term implications of short-term experiments with high CO_2 concentrations. Field studies measuring changes in tree growth in response to acidic precipitation and gaseous air pollutants revealed that annual tree growth has declined (Johnson 1983; McLaughlin, West, and Blasing 1983; Plochmann 1984; Nilsson and Duinker 1987), despite increases in global CO_2 of 25% to 30% since about 1850. Even the growth increases at very high altitudes (LaMarche et al. 1984), parallel with CO_2 increases, are ambiguous at best. For example, the timing of enhanced tree growth at these temperature-limited growth sites coincides more closely with the warming of the past century than with the CO_2 increases.

Forests will respond to changes in climate and CO_2 "fertilization," if at all, as a function of changing competitive advantages among species. Competition negates the simplistic view that all forest trees would benefit from increased CO_2. Instead, growth advantages conferred on one species must incur growth losses in less competitive species in a complex,