CLIMATIC AND POLLUTION INFLUENCES ON ECOSYSTEM PROCESSES IN NORTHERN HARDWOOD FORESTS

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OVERVIEW AND OBJECTIVES

The Michigan gradient study was established in 1987 to examine the effects of climate and atmospheric deposition on forest productivity and ecosystem processes in the Great Lakes region. Four intensively-monitored northern hardwood study sites are located along a climatic and pollutant gradient extending from southern lower Michigan to northwestern upper Michigan. The project continues today, with the following overall objectives: (1) to continue measuring key ecosystem variables at four sites; (2) to understand how carbon allocation, nutrient cycling, and forest productivity respond to differing levels of temperature, moisture availability, and atmospheric deposition; and (3) to quantify sources of temporal and spatial variability in ecosystem processes for use in regional modeling efforts. Additional research designed to investigate the effects of soil temperature and N availability on belowground processes was initiated at the sites in 1993. Objectives of this research are: (1) to quantify relationships between soil temperature and fine root longevity, and root system construction and maintenance costs; (2) to determine how soil nitrogen supply affects fine root construction and maintenance costs, and lifespan; (3) to understand the effects of soil temperature and nitrogen availability on soil respiration; and (4) to quantify the contributions of root and microbial respiration to respiratory flux from the soil.

GENERAL APPROACH

The four study sites extend across a 600 km climate/pollutant gradient in Michigan (Figure 1). All sites are 80 year old second-growth northern hardwood stands dominated by sugar maple (*Acer saccharum* Marsh.). Mean annual temperature increases from 4.2°C at Site 1 to 7.6°C at Site 4. Total annual wet plus dry deposition of NO_3-N increases from 4 kg ha^{-1} to 8 kg ha^{-1} between Sites 1 and 4 (MacDonald et al. 1992), with similar gradients existing for SO_4 and H^+. At each site, three 30 m by 30 m study plots were established in 1987.

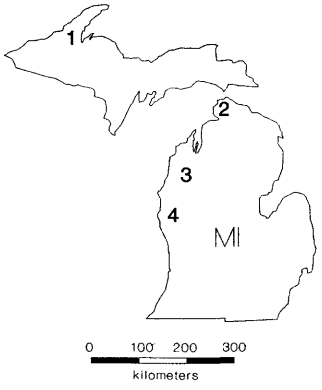

Figure 1. Study site locations.

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The influence of climate on ecosystem processes is being assessed by determining the effects of yearly variation in precipitation and temperature within sites. As length of record becomes sufficient, individual sites are compared to determine if they respond in the same way to climatic variation. The impact of pollutant deposition along the gradient is addressed by comparing rates of ecosystem processes at sites receiving historically different levels of pollutants. Our long-term records of key variables along the climatic/pollutant gradient give us a unique opportunity to study ecosystem processes under real-world environmental stress in an area that is predicted to be greatly affected should global change occur.

Our long-term data base includes the following parameters: forest productivity (basal area growth, height growth, biomass increment, individual tree vigor and mortality), wet deposition, soil solution chemistry, soil and air temperature, soil moisture availability, above and below-ground litter inputs, seed production, leaf and fine root nutrient contents, leaf area index, canopy transmittance, insect defoliation, and soil chemical and physical properties. Variables are measured on different time steps ranging from hourly measurements of soil temperature to annual measurements of tree diameter growth. Some measurements have been continuously recorded since 1987. In many instances, six to eight years of data exist. Measurements of soil and root respiration, soil gas fluxes, leaf and root nitrate reductase activity, microbial biomass, N mineralization, nitrification, and fine root turnover were initiated in the fall of 1993.

PROJECT STATUS

When we began our study, many believed that the substitution of space for time would be confounded by geographic differences in climate and soil, and temporal variation in variables such as leaf area and N flux in litterfall. Measurements along the gradient of insect defoliation, stand leaf area, foliar litter production, net primary productivity, production of flowers and seeds, and nutrient flux since 1987 have, in fact, demonstrated significant year-to-year variability within and among sites (Burton et al. 1991a; Pregitzer and Burton 1991; Pregitzer et al. 1992; Burton et al. 1993; Reed et al. 1994c). Fluxes of reproductive litter and foliar litter were negatively correlated at the stand level, suggesting a direct tradeoff between production of leaf biomass and reproductive biomass (Pregitzer and Burton 1991). Bumper sugar maple seed crops and insect defoliation had large impacts on nutrient cycling, (Pregitzer and Burton 1991, Burton et al. 1993). But in spite of such spatial and temporal variation, there was clear evidence that pollutant deposition had altered vegetation and soil processes along the gradient. MacDonald et al. (1992, 1994) documented a direct relationship between soil solution SO_4^{2-} concentration and flux and SO_4^{2-} deposition. Leaching losses of Ca^{2+} and Mg^{2+} exceeded inputs for all sites along the gradient. Elevated losses of Ca^{2+} and preferential leaching of Mg^{2+} from high deposition sites with coarse textured soils suggest that depletion of cation reserves at poorly buffered sites remain a likely consequence of pollutant deposition. Liechty et al. (1993) measured increased foliar leaching of Ca and Mg at sites receiving higher H^+ deposition, and foliar concentrations of S and Al were positively correlated with increasing SO_4^{2-} deposition along the gradient (Pregitzer and Burton 1992, Burton et al. 1993).

Several effects of climatic conditions on ecosystem processes have been demonstrated at the sites. Lane et al. (1993) studied sugar maple diameter growth over the past fifty years at the sites and showed that productivity was affected by temperature to some degree at all sites, with precipitation increasing in importance at the southern sites. Climatic conditions in the prior growing season affected current season sugar maple growth. Reed et al. (1994c) showed that growth efficiency measures may differ by an order of magnitude in successive years on a site due to natural factors affecting the accumulation of woody biomass. Production dynamics of the northern hardwood forests studied were driven by complex interactions among climatic factors affecting energy storage, insect defoliation, and seed crop production. Year-to-year changes in crown condition largely reflected the gradual decline and mortality of suppressed and intermediate trees, apparently the result of severe drought in 1988 in combination with other stress factors such as defoliation.

Contents of many nutrients in midsummer foliage and litterfall increased from north to south, largely as a consequence of higher foliar biomass production and litter fall at the more southern sites (Pregitzer et al. 1992, Burton et al. 1993). This increase in foliar biomass may be a consequence of increasing temperature and length of

growing season, but also is consistent with the hypothesized effects of chronic N deposition at the southern, higher deposition sites (Pregitzer et al. 1992).

Studies of fine root dynamics were performed at two sites and have shown that fine roots (< 2 mm) dominate total biomass and N litter inputs to soil, accounting for over 55 percent of total biomass and nearly 50 percent of total N returns (Hendrick and Pregitzer 1993a). Rates of fine root turnover were different for the two sites, and it appears that rates of fine root "turnover" (longevity) may be related to soil temperature (Hendrick and Pregitzer, 1993b), a possibility that has not been considered in current models of the effects of global warming on forest ecosystems.

Soils from the sites were incubated for 32 weeks over a range of temperatures to quantify the effects of temperature on kinetics of microbial respiration and mineralization of N and S (MacDonald et al. 1995). Microbial respiration and the net mineralization of N and S increased with temperature at all sites. Rate constants estimated for each site and temperature from these models were not consistently related to temperature. In contrast, estimates of labile C and N pools were strongly temperature dependent. These results suggest the commonly accepted assumptions of constant pool sizes and temperature-dependent rate constants may not be tenable (MacDonald et al. 1995), leading to possible errors in predictions of soil C storage and N availability in response to global warming.

We continue to examine the interacting effects of climate, defoliation, pollutant deposition and seed production on forest productivity and health, fine root dynamics, microbial dynamics, soil solution chemistry, foliar nutrient status, and leaf area. We are now entering a stage where sufficient years of record exist to allow us to assess the relative impacts of these multiple stressing factors on ecosystem processes in northern hardwoods, an important biome type, widely distributed in North America.

MICHIGAN GRADIENT PUBLICATIONS

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